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Report on Ventilation and the effect of Open
Air and Wind on the Respiratory Meta-
bolism, by Prof. Leonard Hill, F.R.S.
(Report made under the Grant for Auxiliary
Scientific Investigation.)



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Report on Ventilation and the effect
of Open Air and Wind on the
Respiratory Metabolism, by Prof.
Leonard Hill, F.R.S. (*Report made
under the Grant for Auxiliary Scientific
Investigation.*)

ARTHUR NEWSHOLME,
Medical Officer,
July 30th, 1914.

The following report has been written for the Local Government Board, and embodies the results of an original investigation into respiratory exchange in man under varying climatic conditions.

In order that the original results incorporated in it may stand in their proper relation, I have included a preliminary survey of the history of the subject, including previous work on it carried out by myself and my co-workers. In the carrying out of this research I have been greatly assisted by Dr. Martin Flack, to whom my best thanks are due.

The early medical writers who treated of the visitation of plague observed that "effluvia emanating from dead corrupted animal matter, even in a state of putrefaction, does not produce fever of an infectious type, and, that when these exhalations seem to engender such a disease, they consist in part, or are mixed with, the *vitiated effluvia*† from the living human body. And that it seems to be an invariable result that the accumulation and stagnation of the *breath and perspiration* of human beings crowded for a period in confined air, and neglecting personal cleanliness, produce plague or fever that may be communicated to healthy persons by contact or respiration." At the time of the black death people sought to escape into "clean air."

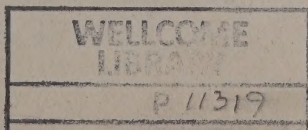
"It was noted that in England the bubonic plague never became epidemical before the beginning of July, and it reached its height in September, after which it declined."

"It required air of a temperature between 60° F. and 80° F. and charged with moisture, to develop its infectious action."

"Hence, when the want of ventilation in the houses concurred with the moist, warm, calm air out of doors, or in other words, with the want of wind, the great ventilator of nature, every squalid inmate of an ill-ventilated apartment became a reeking sphere of pestilence *impregnating the motionless air* of his dwelling and neighbourhood with the fatal elements of a loathsome death."*

* Bernan. "History and Art of Warming and Ventilating," London, 1845.

† Italics by L. H.



"One cannot contemplate," says the same early Victorian writer, "without astonishment the delusive and futile means that were followed to avert and mitigate the dire contagion, nor think without humiliation that opinions prevented reliance on the promptings of nature, *to keep themselves clean and to admit fresh air into their habitations: the only rational and effectual means of escape from danger*, and by following which modern physicians not only prevent infection and make it harmless, but have eradicated the epidemical plague itself from England."

Before the discovery of the microbic origin of infective disease the pioneers in sanitary reform, while thus rightly associating the spread of pestilence with the herding of human beings in confined quarters and filthy conditions, attributed the cause of most epidemic diseases to poisonous exhalations of the human body, while malaria was attributed by them to the exhalations of marsh and night air. Thus the belief in such exhalations has almost become an article of popular faith. In the writings of the great prison reformer, Howard,* we find "the poisonous effluvia" of the horrible dungeons he visited regarded as the cause of "gaol" and other fevers which cleared off not only the unfortunate occupants of the gaol, but not infrequently those of the bar and bench who tried the prisoners. During his tour of inspections Howard states that his own clothes were often so saturated with foul effluvia that he was obliged to travel with the windows of his carriage open. He quotes Hales and Pringle as to the pernicious effect of "putrefied air" and Bacon, who, in his "Natural History" observes:—"The most pernicious infection next to the plague is the smell of a jail." He found prisoners crowded into dungeons for fifteen hours out of the twenty-four; that there was no court or open space; that gaolers often stopped up the windows (to avoid paying the window-tax). He refers to the Black Assize at Oxford in 1577, and to the Lent Assize at Taunton in 1730, where prisoners, brought into court after long confinement in offensive dungeons, infected all present, causing a terrible mortality. In 1750 the Newgate prisoners infected the Court at the Old Bailey and forty died including two judges and the Lord Mayor.

To quote a few observations from the notes he made on scores of institutions:—

"At the great Casern in Vienna there were only two holes in a room filled with inmates to the number of 86 at night, who slept in their clothes and chained to the floor. At the Hotel Dieu, Lyons, no windows were open, the medical men and sisters being prejudiced against fresh air. At Westminster Hospital the upper sashes of the windows were not movable, at St. George's Hospital, too, the windows were shut and too small. The windows of the Dublin hospitals and the Oxford County Hospital were all shut, the wards being very offensive."

Howard further draws attention to the state of dirtiness of many public institutions and to their swarming with vermin. The

* "State of Prisons of England and Wales," London, 1792. "Lazarettos of Europe," Warrington, 1789. cf. Sweeting, "The Sanitation of Public Institutions," Howard Prize Essay, 1883.

prisons were dirty and never washed. Hospitals "were dirty and the walls black and filthy, and swarming with vermin." He found an absence of sewers or, when found, they were offensive. Numerous buildings were destitute of chimneys, fireplaces or fuel. He found the inmates of public institutions badly clothed and destitute of linen, they often had no bedding, not even straw. If there were beds they were old and dirty. There was no infirmary or attempt at isolation of the sick in many gaols. At many institutions the inmates were starved or badly fed. In many close confinement and exercise were the rule.

Howard advised daily exercise. He deprecated close, offensive, loathsome, and damp atmospheres in public institutions, and traces pale, sickly countenances, "gaol" or "hospital fever (typhus)," slow fever (typhoid), scurvy, smallpox, gangrene, septicaemia, and cutaneous disorders to their pernicious influence. He commended a cool, fresh, pure atmosphere, showing how it tends to lower mortality. The impure air of holds of ships was regarded as one of the causes of scurvy.

He recommended that "windows be opposite, level with ceiling, and the upper sashes always open; that the wards be scraped and limewashed annually, washed weekly, that airy rooms be built and provided with fireplaces; that there be exercise courts and a provision of baths, good food, clean linen in plenty, proper sewers, an infirmary for each gaol and inspectors."

A surgeon of the Maidstone Prison, a pioneer in reform named Day, following the precepts of Howard, succeeded in totally stamping out the fever "by washing the walls and ceilings with boiling lime, throwing quicklime from time to time down the necessaries and along the drains, frequently changing the linen and clothes, having a constant attention to cleanliness, and washing the men daily with warm suds, and drying their clothes every week upon an oast of sulphur and giving them nutritive food." He also sprayed the air with boiling lime water "the effect resembled the earth being cooled, in a sultry hot day, by a hasty shower of rain."*

The pioneer sanitarians of the nineteenth century believed no less in poisonous effluvia. After a careful examination of the enormous amount of evidence which he had collected, Chadwick† thus summed up the conclusion of the whole matter:—

"That the various forms of epidemic, endemic, and other disease are caused or aggravated, or propagated, chiefly amongst the labouring classes by *atmospheric impurities*‡ produced by decomposing animal and vegetable substances, by damp and filth, and close and overcrowded dwellings. That such disease, whenever its attacks are frequent, is always found in connection with the physical circumstances above specified, and that when these circumstances are removed by drainage, proper cleansing, better ventilation, and other means of *diminishing atmospheric impurity*,

* Bernan's "History and Art of Warming and Ventilating," London, 1845, vol. i, p. 203.

† "Survey into the Sanitary Conditions of the Labouring Classes of Great Britain," *cit.* after Sir W. Job Collins.

‡ Italics by L. H.

the frequency and intensity of such disease are abated, and where the removal of the noxious agencies appears to be complete, such disease almost entirely disappears. That cases of smallpox, of typhus, and of others of the ordinary epidemics occur in the greatest proportion in common conditions of *foul air* from stagnant putrefaction, from bad house drainage, from sewers of deposit, from excrement-sodden sites, from filthy street surfaces, from impure water, and from overcrowding in private houses and in public institutions. That the entire removal of such conditions by complete sanitation and by improved dwellings is the effectual preventive of diseases of these species, and of ordinary, as well as of extraordinary, epidemic visitations."

In her "Notes on Nursing," Miss Nightingale says:—

"I was brought up, both by scientific men and ignorant women, distinctly to believe that smallpox, for instance, was a thing of which there was once a first specimen in the world, which went on propagating itself in a perpetual chain of descent, just as much as there was a first dog (or first pair of dogs), and smallpox would not begin itself any more than a new dog would begin without there being a parent dog. . . . Since then, I have seen with my eyes, and *smelt with my nose*, smallpox grow up in first specimens, either in close rooms or overcrowded wards, where it could not by any possibility have been caught, but must have begun. . . . I have seen, for instance, with a little overcrowding, continued fever grow up, and with a little more typhoid fever and with a little more typhus, and all in the same ward or hut. Would it not be far better, truer, and more practical if we looked on disease in this light?"

While the theory of the spread of infective disease has now almost wholly changed, a few sanitarians, such as Sir William Job Collins, still put forward the view that the infecting agents can be evolved by filthy conditions.* It is now generally recognised that a specific microbe is the cause of each infectious disease, and that infection is spread not by poisonous exhalations but by:—

(1) biting insects which directly transfer infected material from one individual to another (flies, fleas, bugs, lice);

(2) flies which directly transfer infected material from human evacuations to food;

(3) direct infection of milk or water supply by sewage or by the wind-borne dust of dried human evacuations;

(4) human carriers of disease, *e.g.*, the milkman, who after recovery from the disease, continues to pass a virulent strain of typhoid bacilli in his urine, and with his hands infects the milk he sells; also that other kind of carrier, who, when infected, has the disease so slightly that it is not recognised;

(5) spray infection—the direct passage of bacteria from the respiratory passage of one person to another;

(6) the direct contact of an infected part of one man's body with the body of another.

It is recognised, too, that infecting bacteria may change their characteristic qualities, and be exalted in virulence in some, attenuated in other conditions; that immunity may be gained by

* Lecture to the Congress of the Royal Sanitary Institute, 1913.

infection with an attenuated widely spread strain of the disease; that a mixed infection may be the cause of heightened virulence, *e.g.*, streptococcic infection of the throat in scarlet fever; that one epidemic may aid the progress or increase the severity of another.

It has become clear that the prevention of bubonic plague, malaria, yellow fever, typhus and relapsing fever, sleeping sickness depends on the suppression of biting insects, of the specific carriers of the specific microbe. Looking at Day's proceedings in Maidstone Gaol, we see how admirably they were adapted for the destruction of vermin—of the louse which spreads typhus.

Evidence accumulates that typhoid fever and summer diarrhoea are spread by flies. The great fall in the mortality from pneumonia in the Panama Canal district has been coincident with the destruction of flies. The direct mouth to mouth infection by saliva spray is now regarded as far the most potent cause of phthisis, common colds and influenza. We have every reason to believe that saliva spray infection also spreads scarlet fever, diphtheria, measles, mumps, etc. While the whole outlook has changed as the result of scientific investigation, the central belief of the pioneers of sanitary reform remains unconfirmed. It is now recognised that while an offensive smell may be a warning of evil conditions of the environment, it does not necessarily signify a poisonous exhalation. On the other hand, the breathing of dusty atmospheres, which have no offensive odour, increases respiratory disease and shortens life. Masons and grinders who work in stone containing free silica, such as quartz, granite, and flint, and who breathe silica dust, suffer extraordinarily from phthisis, and not necessarily because their lungs are injured by the sharp insoluble particles, and so exposed to infection. The silica may have some chemical and physical action which requires elucidation. Workers in limestone, or stones containing compound silicates such as glass and emery, the particles of which are no less hard, as well as workers among coal and animal or vegetable dusts, suffer, on the other hand, from asthmatic complaints, but not especially from phthisis.* The particles of such dusts are probably dissolved or rendered harmless by the body fluids. Just as the poisonous trade dusts, such as that of lead, have been investigated, and precautions taken against them and against those poisonous gases which endanger the workers in mines and chemical processes, so precautions can be taken against silica and other dusts which damage the lungs.

It is abundantly clear from the history of mankind that he has an enormous resisting power against dirt, stench, and infection by vermin, otherwise none would have survived. It is equally clear that when epidemics have arisen they sweep with far the greatest fatality through the squalid, dirty and overcrowded quarters of the poor. There are seasonal and other conditions, of which we know nothing, which control epidemics. Forty years ago scarlet fever was dreaded for its high mortality, now its mortality rate is one-sixth that of measles.

* Collis. "The Effects of Dust in Producing Diseases of the Lungs," xvii. Intern. Congress of Med., 1913. The granite metalling of roads and the advent of the motor car have led to the inhalation of silica dust by the common user of the roads.

In the squalid conditions of the poor there are many possible factors at work, *e.g.*, massive direct spray infection from over-crowding in confined atmospheres, massive infection by vermin, massive streptococcal or staphylococcal infection arising from dirt of person, clothes, bedding, etc., reduction of immunity from bad feeding, confined and stagnant air, want of exercise, over-work.

There has been an effort to minimise the importance of the effect of environment. We are told by some eminent eugenists that stock is everything—inborn immunity. That the weakest stock drifts into the worst back-to-back houses and hence the higher death rates therein. The history of our hospitals, of the expulsion by Lister of hospital gangrene and all sepsis from surgical wards, shows on the other hand that in some directions at least the influence of environment is supreme. So, too, does the discovery of insect-borne disease and the suppression of yellow fever, malaria and pneumonia in the Panama Canal district. Likewise the suppression of typhus, the limitation of plague, and sleeping sickness. No inborn immunity will explain the different effects of silica and limestone dusts.

How greatly the environment of the poor has improved in the last half century is seen if we contrast the description of property purchased by Miss Octavia Hill with the courts and streets of tenements of to-day.

Miss Octavia Hill* describes the condition of the slum houses she purchased, thus:—

“The set last purchased was a row of cottages facing a bit of desolate ground occupied with wretched, dilapidated cowsheds, manure heaps, old timber, and rubbish of every description. The houses were in a most deplorable condition—the plaster was dropping from the walls; on one staircase a pail was placed to catch the rain that fell through the roof.” All the staircases were perfectly dark, the banisters were gone, having been burnt as firewood by the tenants. The grates, with large holes in them, were falling forward into the rooms. The wash-house, full of lumber belonging to the landlord, was locked up: thus the inhabitants had to wash clothes, as well as to cook, eat and sleep in their small rooms. The dustbin standing in the front of the houses, was accessible to the whole neighbourhood, and boys of ten dragged from it unseemly objects and spread them over the court. The state of the drainage was in keeping with everything else. The pavement of the back-yard was all broken up, and great puddles stood in it, so that the damp crept up the outer walls. One large but dirty water-butt received the water laid on for the houses: it leaked, and for such as did not fill their jugs when the water came in, or who had no jugs to fill, there was no water.”

In another set of houses purchased by Miss Octavia Hill “the dustbins were utterly unapproachable, and cabbage leaves, stale fish, and every sort of dirt were lying in the passages and on the stairs. In some the back kitchen had been used as a dustbin, but had not been emptied for years, and the dirt filtered through the

* “Homes of the London Poor,” *cit.* after Wanklyn “Working-class Home Conditions in London.” Section of Epidemiology, Roy. Soc. of Med., Oct. 24th, 1913.

front kitchens, which were the sole living and sleeping rooms of some families. In some, the kitchen stairs were many inches thick with dirt which was so hardened that a shovel had to be used to get it off. . . . The wood was eaten and broken away: windows were smashed and the rain was coming through the roofs."

From the Registrar-General's returns and those of the Medical Officer of Health of the London County Council, Dr. Wanklyn† estimates that over 2,300,000 people, or half the population of London, are now housed in "tenements" of one to four rooms. Investigating a street of such houses, she says, "the stairs and passages were filthily dirty: the sides of the passages were greasy brown, and black, and although the front and back doors were open and air was passing through freely, the house stank." The accommodation of the top tenement in these houses is a front room, 14 ft. by 11 ft. by 6 ft. 6 ins., with a kitchen fireplace and a cupboard set in the wall, and a back room, 9 ft. by 7 ft. by 6 ft. 6 ins., which has no fireplace. The woodwork is said to be infested with bugs. "There is no place for storing food, or crockery, or knives and forks and the rest, except one wall cupboard in the front room. There is no scullery, no sink, or even water for washing up, no draining board or any place in which to handle clean things: no water-closet nearer than at the foot of thirty-six stairs; the water-closet is in the back-yard, and is used in common by thirteen people in the house; no one person is responsible for its cleanliness. There is nowhere for the children to play. No coal or wood store, no cold water tap nearer than the back-yard.

Nevertheless, while the writer's inspection of tenements in other districts shows these conditions are truly stated, the streets and courts are well kept by the sanitary authorities. There is no collection of filth round the houses, and the water supplied is good. The children have paved streets and courts and the open air to play in, and for them is the interest of the streets, and shops, movement and life, and the romantic lights and shadows of evening. Given shelter, warmth, food, and companionship the human race gains 99 per cent. of that which makes for its content unless educated to other desires and aspirations.

A vast improvement has been made in the external environment of the dwelling so far as concerns the water supply, drainage and cleanliness. Inside, the tenement is a part of a "made-down" house, not built for the use it is put to, and the occupants require more light, fresh air and those structural conditions and fittings which are an incentive to cleanliness and make for economy and health.

It is inside the tenements, not outside, that the conditions demand immediate reform, and the scientific basis for impelling such reform and the building of garden cities requires clearly stating.

It is to the conditions of temperature and lack of movement of the air, leading to a heat stagnation in the body and monotonous conditions of cutaneous excitation, that considerable attention

† Wanklyn *loc. cit*

will be devoted in this paper, but what may be termed the "chemical" theory of ventilation will be first examined in detail. As has been said, the evil smell of crowded and dirty rooms is still accepted as unequivocal evidence of the existence of a volatile poison in exhaled air. The public still believe in this poison. Not only has much of the practice of ventilation been based on the chemical theory, but the good effects which are recognised to follow from open-air treatment, have been attributed to the chemical purity of the air.

The evil effects of confined and crowded rooms, according to the chemical theory, leaving aside infection, are attributed to the following suppositions:—

- (1) that the air becomes impoverished of oxygen;
- (2) that it contains excess of carbon dioxide gas;
- (3) that it contains an organic poison from the expired air which has been added to the atmosphere.

Little attention has been paid to such points as the temperature and movement of such an atmosphere or to the amount of water vapour contained in it. Yet common observation shows that it is of the heat and want of movement of the air that people always complain: "How close and warm it is." "There is not a breath of air," etc.

THE SUPPOSED DIMINUTION OF OXYGEN.

The oxygen in the most crowded room is never diminished by more than about 1 per cent.—since cracks and crannies are always admitting the outside air. This is seen from the following table:—

Open country or sea	...	...	...	...	...	20·95
Streets of London	...	...	...	...	...	20·888
Backs of houses	...	...	...	...	...	20·70
Pit of a theatre (11.30 p.m.)	...	...	...	...	...	20·75
Court of Queen's Bench	...	...	...	...	...	20·65
Lecture theatre (before and after lecture) (Sorbonne)	...	...	...	...	...	20·28–19·86
Cowhouse	...	...	...	...	...	20·75

(Russell).*

Such a diminution of 1 per cent. has no physiological effect. Indeed, for the purposes of open-air treatment cases are sent to health resorts 5,000 feet up in the Alps, where the partial pressure of oxygen is considerably less than ever it can be in the most crowded room.

The barometer may vary at sea-level between 28 and 31 inches—equivalent to a 10 per cent. variation in the partial pressure of oxygen in the atmosphere.

So long as there is present a partial pressure of oxygen sufficient to change most of the hæmoglobin of the venous blood into oxyhæmoglobin during its passage through the lungs there can arise no lack of oxygen. At sea-level the pressure of oxygen in the pulmonary alveolar air is about 100 mm. Hg.—only two-thirds of that in the atmosphere. Exposed to only half this pressure, the hæmoglobin is more than 80 per cent. saturated with oxygen. A person not exerting himself will fail to observe any effect until the oxygen has been reduced to 12 to 10 per cent. of an atmosphere,

* Russell, F. A. R. "The Atmosphere in Relation to Human Life and Health." Smithsonian Miscellaneous Collections, vol. xxxix, 1896, No. 1,072.

and consciousness will not be lost until the percentage sinks below 7 per cent.

People live, work and play in the Andes at a height of 9,000 to 14,000 ft., where the partial pressure of oxygen is but 14 to 12 per cent. of the atmosphere. The Indians there are a hardy and vigorous race, with broad, long and very capacious chests. The inhabitants of the lofty plateaux of Thibet are remarkable for their physical vigour and activity. No disturbance is felt by the inhabitants or by those who reach these great altitudes slowly and by easy stages. The only disability to an acclimatised man is diminished power for severe exertion, but a greater risk arises from want of oxygen to cases of heart disease, pneumonia, and in chloroform anæsthesia at these high altitudes. The newcomer who is carried by the railway in a few hours to the top of Pike's Peak or the Andes may suffer severely from mountain sickness, especially on exertion, and the cause of this is want of oxygen. Acclimatization is brought about in a few days' time. The pulmonary ventilation increases, the circulation becomes more rapid. The blood is concentrated by the passage of water from the plasma into the tissues. The red corpuscles thus circulate more frequently. The relation of acids to bases of the blood is altered, so as to compensate for the carbonic acid removed by increased breathing. As the partial pressure of CO_2 in the alveolar air of the lungs is lowered, that of the oxygen is made higher. New red corpuscles are formed and the total amount of hæmoglobin increased.

Altitude sickness results before acclimatization is attained at the time when the want of oxygen leads to an increase of lactic acid in the blood and before the adjustment of the acids and bases of the blood has taken place. But no want of oxygen results from the attenuation of the oxygen such as occurs in crowded rooms at sea-level. The writer has had several students confined in a hermetically sealed chamber and they have been quite comfortable with the percentage of oxygen so low that a match would not burn (less than 17 per cent.)—so long as the air has been maintained by a fan in movement and the cooling of their bodies assured. Coal miners working at the face constantly labour in an atmosphere wherein the oxygen is diminished 1 to 2 per cent., they follow a healthy occupation and are remarkably free from phthisis. In Spain at altitudes above 4,000 ft., phthisis is unknown and the increased pulmonary ventilation probably has much to do with this immunity. It is evident, then, that owing to the combining power of hæmoglobin and the power of adjustment of the blood the respiratory exchange and metabolism of an animal is independent within wide limits of the partial pressure of oxygen. So long as the body secures enough oxygen for its functional needs an excess has no influence upon it beyond producing a slowing of the pulse.* The rate of combustion of the tissues is set by the nervous system and cannot be accelerated by increasing the supply of oxygen. The inhalation of oxygen acts beneficially only when there is want of oxygen, as in pneumonia or during severe exertion. It has no effect on the resting man.

* Benedict and Higgins, *Amer. Journ. of Physiol.*, vol. xxviii, 1911; J. Parkinson, *Journ. Physiol. Proceedings*, 1912.

THE SUPPOSED EFFECT OF EXCESS OF CARBON DIOXIDE.

Analysis show that in a confined atmosphere the amount of CO_2 never rises to any great extent, *e.g.*:—

London (summer average)	·0379
Court of Chancery	·20
Workshop	·30
Pit of theatre	·32
Crowded meeting	·365

(Russell).

A great deal has been made of the ill effects of excess of carbon dioxide in the air—and in regulations for certain trades under the English Factory Acts only a few parts per 10,000 are permitted in the air. Physiological enquiry has, however, proved that the excess in the atmosphere cannot enter the body.

This is because the respiratory centre acting in response to the hydrogen ion concentration of the blood normally keeps the CO_2 content of the pulmonary air constant at about 5-6 per cent. (Haldane and Priestley).*

The only result from breathing 5 per cent. CO_2 , a slight excess to the physiologists but regarded as enormous by the hygienist, is an unnoticeable increase in the ventilation of the lungs. The increased ventilation is so adjusted as to keep the concentration of CO_2 in the lungs at the normal 5 to 6 per cent. of an atmosphere. When we take gentle exercise and produce more CO_2 in our bodies, the pulmonary ventilation is similarly increased, and thus the concentration of CO_2 in the lungs and blood is kept constant.

Haldane and Priestley found that with a pressure of 2 per cent. of an atmosphere of CO_2 in the inspired air the pulmonary ventilation was increased 50 per cent.; with 3 per cent., about 100 per cent.; with 4 per cent., about 200 per cent.; with 5 per cent., about 300 per cent.; with 6 per cent., about 500 per cent. With the last panting is severe, while with 3 per cent. it is unnoticed until muscular work is done, when the panting is increased 100 per cent. more than usual. With more than 6 per cent. the distress is very great, and headache, flushing, and sweating occur. With more than 10 per cent. there occurs loss of consciousness after a time, but no immediate danger to life. Even exposure to 25 per cent. may not kill an animal within an hour or two. Such high concentrations, when breathed with sufficient O_2 , poison the heart and lower the blood pressure.

It is only when the higher concentrations of CO_2 are breathed, such as 3 to 4 per cent. of an atmosphere, that the respiration is increased so that it is noticeable to the resting individual; but percentages over 1 per cent. diminish the power to do muscular work, for the deep breathing due to the work is increased by the effect of the CO_2 in the atmosphere. In submarines it is found that the men can endure concentrations up to $3\frac{1}{2}$ per cent. without any great difficulty, the oxygen at the same time being correspondingly diminished.

The writer and Martin Flack,† found that rats huddled together

* *Journ. Physiol.*, xxxii, p. 225, 1905.

† Hill, Flack, McIntosh, Rowlands, and Walker. "The influence of the atmosphere on our health and comfort in confined and crowded places." *Smithsonian Miscellaneous Collections*, vol. lx, No. 23, 1913.

in their sleeping chamber breathe from 2·8-5 per cent. of CO_2 in preference to being out in the cold open part of their boxes. They come outside when the air within becomes too warm and moist. In the room of a brewery where CO_2 is compressed into cylinders the men work regularly in an atmosphere of '9 to 1·48 per cent. of CO_2 . No deleterious effects have resulted after many years at the employment (Hill, Flack, etc.*).

Lehmann found in a brewery 1·5 to 2·5 per cent. of CO_2 in the air of the fermentation rooms. This was breathed by five to eight workers for hours every day with no ill effects. All were strong, healthy men, some having done the work for years.

At each breath we rebreathe into our lungs the air in the nose and large air-tubes (the dead-space air); about one-third of the air breathed by a resting man is dead-space air. Thus, no man breathes in pure outside air into his lungs, but air contaminated perhaps by one-third or (on deep breathing during muscular work) by one-tenth with his own expired air. When a child goes to sleep with its head partly buried under the bed clothes, and in a cradle confined by curtains, it rebreathes the expired air to a still greater extent; and so with all animals that snuggle together for warmth's sake.

To rebreathe one's own breath is a natural and inevitable performance, and to breathe some of the air exhaled by another is the common lot of men who, like animals, have to crowd together and husband their heat in fighting the inclemency of the weather.

Carbonic acid can therefore be dismissed as having nothing whatever to do with the ill-effects of confined atmospheres.

THE SUPPOSED EXISTENCE OF ORGANIC POISON IN EXPIRED AIR.

A great deal has been made of the supposed existence of an organic poison in expired air in all the popular books on hygiene, but when we come to examine that question we find that there is no evidence worth anything at all as to the existence of this poison.

Evidence for such a poison was first brought forward by Brown-Séquard and D'Arsonval.† They expired through a vessel surrounded with ice and the water exhaled in the breath was condensed. They took that condensation water and injected it into animals, which were said to be poisoned by it. Therefore, it was argued, there was poison in this condensation water which was exhaled. Another experiment was to put a number of animals in separate glass vessels and draw the air from vessel to vessel, so that animal No. 6 was breathing the air which had come through the other five vessels where the other five animals were. They said that Nos. 6 and 5 got poisoned, while Nos. 1 and 2 remained in perfect health. A great many trustworthy and skilled investigators have now repeated these experiments, and found no evidence in favour of the existence of these poisons (Dastre and Loys, Russo Gilberti and Alessi, Hermans, Lehmann, Haldane and Lorrain Smith, Jessen, Paul, Ercklentz, etc., etc.). It has been shown that why these animals died in the last boxes, Nos. 5 and 6,

* Hill, Flack, McIntosh, Rowlands, and Walker. "The Influence of the atmosphere on our health and comfort in confined and crowded places." Smithsonian Miscellaneous Collections, vol. lx., No. 23, 1913.

† For references see Hill, Flack, etc., *loc. cit.*

was because errors of technique were made; the tubes were wrongly placed, and leaked so that the current of air did not come through, and the animals were asphyxiated from want of air; or else the current of air was made so slow that the last animals were given something like 15 per cent. of carbonic acid to breathe, a poisonous amount.

The writer and Martin Flack have tackled the question in a very simple way.* They took a number of deep boxes and put a number of guinea-pigs and rats at the bottom having the lids shut down to such an extent that day and night there was more than 1 per cent. of carbonic acid in the boxes. There the animals lived; thoroughly cleaned and well-fed, and breathing in the exhalation of their own breath day after day, with the ventilation so arranged that at least 1 per cent. of carbonic acid (produced by themselves) was in the boxes. These animals did not suffer; they lived in the boxes for months. They begot young under those conditions. They were removed when pregnant to other boxes because such conditions were not favourable to the mothers actually giving birth to the young. Young ones placed in the boxes exhibited no sign of poisoning, but grew and thrived.

In regard to the first type of D'Arsonval experiment the evidence has been conflicting, but the most trustworthy workers agree that the fluid condensed from the pulmonary exhalations of man has no toxic or specially injurious effect when injected into animals, and there is no evidence that such fluid contains an organic poison. In the experiments of Billings, Weir Mitchell, and Bergey,† the fluid was collected with great care in sterilized apparatus, and was proved to be sterile; it was warmed to body temperature, and was injected without result in doses in some instances less, in others greater, than the smallest quantities that were used by Brown-Séquard and D'Arsonval with fatal effects.

Peters tested the condensation fluid obtained from human breath on the frog's heart. It had no poisonous effect. Recently Weichardt‡ claims to have found traces of a "kenotoxin" in expired air. This, he says, is a protein decomposition product of high molecular weight obtainable in the juice expressed from fatigued muscles. He obtained the condensation fluid from the expired air of a fatigued man of 60 years who breathed through wadding for two hours. The fluid was expressed from the wadding. He claims to have obtained a poisonous effect from this and also from fluid expressed from blotting paper exposed in a room crowded with sleepers. The fluid was concentrated by evaporation, and 1 cc. or more was injected into a mouse.

Inaba§ carried out similar experiments, and reached the conclusion that the mice were poisoned no less by an equally large dose of distilled water. Thus 0.3 to 0.7 cc. gave no result, while 1 to 1.5 cc. made the mice ill. So, too, with distilled water. To put 1 or 1.5 cc. of water into a 13-gram mouse is the same as injecting five litres into a 60-kilogram man.

* Hill, Flack, etc., *loc. cit.*

† Billings, Weir Mitchell, and Bergey. *Smithsonian Contributions to Knowledge*, vol. xxxix, 1895.

‡ "Arch. f. Hygiene," vol. lxxiv., p. 185, 1911.

§ "Ztschr. f. Hygiene," vol. lxviii, p. 1, 1911.

Weichardt* rejoined that the respiratory condensation fluid gives the guaiacum reaction, and so must contain some trace of protein. He also said the mouse was not affected by 1 cc. of the concentrated condensation water, if heated to dryness and redissolved, while it was affected by the same dose of unheated condensation water.

He gave details of only one or two such experiments. We now know that either distilled water or isotonic saline solution, when kept in the laboratory, may produce toxic symptoms, especially when large doses are injected. The solution or water becomes infected with bacteria, and although sterilized by boiling, when injected intravenously into men may produce febrile and other disturbances, such as have been observed after the injection of salvarsan. These mischances have been altogether prevented by the use of freshly prepared, pure, sterile salt solution.† The toxic effect is due to the dosage of dead bacteria injected with the water. The symptoms are shivering, fever, and cyanosis, vomiting, headache, and pain in the back lasting about four hours.

The only conclusion which can be drawn from the above is that the evidence in favour of the existence of poison in the condensation water is entirely unsubstantiated. The negative results obtained by so many capable workers are convincing, while the few positive results cannot be accepted in the absence of proper controls. To inject one-thirteenth of its body weight of water into a mouse is an absurd experiment. Recently Rosenau and Amoss‡ have brought forward evidence of another kind which seems to show that traces of protein may pass away in the expired air, at any rate under their experimental conditions. They breathed through a Drechsel flask, interposing a plug of cotton wool, for 6 to 10 hours, 10 to 20 cc. of condensation fluid being so obtained; 5 to 10 cc. of this fluid was injected into guinea pigs, and a month later 0.2 cc. of human serum was injected either into the heart or into the brain. Symptoms of anaphylactic shock occurred in many of the animals; but, be it noted, several of the experiments gave negative results, and in particular some in which a double plug of glass wool was employed. It seems to the writer that in breathing through a tube droplets of saliva will be carried away from the mouth, and the glass wool in time will become wet through. When this happens, saliva will be carried into the condensation water, thence the positive result of the test.

The writer, together with Martin Flack and J. McIntosh,§ has tried the experiment in a simpler manner. He took guinea-pigs and rats, and put them (to live together) at the bottom of boxes such as have been described. There they have lived week after week, the guinea-pigs breathing the rats' exhaled air (and *vice versa*). At the end of several weeks a trace of rats' serum was injected into the ear vein of ten guinea-pigs with no result at all. If there was any protein exhaled in the rats' breath, that protein

* Weichardt and Stötter, "Arch. f. Hygiene," vol. lxxv, p. 265, 1912.

† McIntosh and Fildes, "Syphilis," pp. 200, 207. Arnold, London, 1911. *Lancet*, March 9th, 1912.

‡ *Journ. Med. Research*, Boston, 1911, vol. xxv, p. 35.

§ Hill, Flack, McIntosh, etc., *loc. cit.*

would be breathed in by the guinea-pigs. Rosenau and Amoss assert there is such a volatile protein, and that an inhalation into the lung goes straight into the blood. They go so far as to say that people who live with horses—hostlers and so on—may become sensitized by breathing the exhalations of horses, and that is why some are found to be sensitized to a first dose of antidiphtheric serum. They overlook the hair and epithelial scales which a hostler rubs off a horse—in order to prevent the breathing of which he makes that peculiar hissing noise. These contain protein and get into the throat and respiratory tract. But there is no evidence that foreign protein so absorbed produces the anaphylaxis phenomenon. Not a single guinea-pig was made ill in the writer's experiments. A month later another trace of rat serum was put into those same guinea-pigs. The first dose had sensitized them, and every single guinea-pig that received the second trace rolled over and died. How sensitive they had become was shown by the fact that in one case the syringe was put into the ear and missed the vein; the syringe was squeezed the least little bit, and a trace of the rat serum went into the tissues of the ear, not into the vein. Before the syringe could be inserted into the vein the animal died, poisoned by the minute trace which went into the tissues of the ear.

"Condensation water" has been injected into sensitized animals with no ill results (Hill, Flack and McIntosh, etc.). Conversely other guinea-pigs have been injected intraperitoneally with 5 cc. of water obtained from that condensed on a piece of glass covering a box containing twelve rats. The injection caused no ill-effects. Twelve guinea-pigs have been injected intraperitoneally with doses varying, according to the size of the animal, from 3-5 cc. of this condensation water. Subsequent intravenous injection a month later with 0.2-0.3 cc. of rat's serum in no case caused any anaphylactic symptoms. A further intravenous injection of 0.2 to 0.3 cc. of rat's serum evoked marked anaphylactic symptoms, resulting in death in all but one, which, however, suffered severely and subsequently recovered. One of the young, born after the injection of rat's serum into the mother, was killed by an intravenous injection of 0.1 cc. of rat's serum.

Similarly, two dogs injected with the condensation water obtained by keeping guinea-pigs in a confined space showed no symptoms of anaphylaxis when guinea-pig's serum was subsequently injected.

Such experiments show that the claim to the presence of an organic (protein) poison in exhaled air cannot be substantiated.

THE EFFECTS OF HEAT STAGNATION.

While evidence in favour of the chemical view is lacking, evidence in favour of the view that the discomfort of confined atmospheres is really due to the temperature—excess of water vapour and lack of air movement causing heat stagnation—is very convincing.

No less than 30 years ago Hermans* found the evidence in regard to the bad effect of the chemical impurities insufficient, and sug-

* "Arch. f. Hygiene," vol. i, 1883, p. 1.

gested that the results of bad ventilation are thermal in origin. Susceptible individuals suffer from oppression, headache, sickness, and may faint under certain conditions in crowded rooms. The symptoms resemble those experienced in the open air on excessively hot and humid days. The axillary temperature may be raised 0.3° to 0.6° C. in a hot theatre. Heat and moisture increase very greatly in crowded places where the occupants are jammed together and the usual channels of dissipation of body heat are checked. Flannel and linen garments may increase in weight 13 to 14 per cent. The wetness of the clothes increases the unpleasant feelings and the danger of chill on coming out of warm rooms into the outer air.

Under the direction of Flügge* a series of admirable experiments have been carried out on this question in the Institute of Hygiene in Breslau by Heymann, Paul, and Ercklentz.

Normal individuals were placed in a cabinet of 3 cubic metres capacity, and shut within it for periods up to four hours until the CO_2 percentage rose to from 1.0 to 1.5. No symptoms of illness or discomfort were felt, and the chemical impurity of the air had no influence on the power to carry out ergographic tests, or mental computations, so long as the temperature and moisture of the air were kept low. Paul shut a man in the chamber for $4\frac{3}{4}$ hours. The temperature rose to 24° C., the relative humidity to 89 per cent., the CO_2 to 1.2 per cent. He was very uncomfortable. Those who, from outside the chamber, breathed the air within through a tube and mouthpiece, felt no discomfort. Immediate discomfort was felt by one who went into the chamber. In another experiment the temperature was 30.2° C., relative humidity 87 per cent., CO_2 1.1 per cent. Symptoms of discomfort were pronounced although the subject breathed pure air from outside through a mouthpiece. The symptoms were allayed by a fan which impelled the air in the chamber at a rate of a few metres per second.

When the chamber was cooled to 17° C. there were no symptoms of discomfort although the CO_2 rose to 1.6 per cent.

The writer, with Martin Flack, R. A. Rowlands, and H. B. Walker,† has confirmed and extended these results. They used an experimental chamber, constructed of wood with large observation windows, and rendered air-tight by filling up all cracks with putty and pasting the interior with several layers of brown paper. The temperature could be elevated by means of electric heaters, or cooled by a coil through which cold water could be circulated. The amount of water vapour could be raised by placing vessels of water over the heaters, and the air moved by means of electric fans placed in the roof. Wet and dry bulb readings were taken at about chest height. The chamber held approximately 3 cubic metres of air. In one class of experiments seven or eight students were shut within the chamber for about half an hour, and the effect of the confined atmosphere upon them observed. They were kept there until the CO_2 reached 3 to 4 per cent., and the oxygen had fallen to from 17 to 16 per cent.

* "Ztschr. f. Hygiene," vol. xlix, 1905, pp. 363, 388, 405, 433.

† Hill, Flack, etc., *loc. cit.*

The wet-bulb temperature rose meanwhile to about 82° to 85° F., and the dry-bulb a degree or two higher. The students went in chatting and laughing, but by and by, as the temperature rose, they ceased to talk, and their faces became flushed and moist. Some tried to light a cigarette (to relieve the monotony of the experiment), and were puzzled by their matches going out. They had not sensed the diminution of oxygen, which fell below 17 per cent. Their breathing was slightly deepened by the high percentage of CO_2 , but no headache occurred in any of them from the short exposure to from 3 to 4 per cent. CO_2 . Their discomfort was relieved to an astonishing extent by putting on the electric fans placed in the roof. Whilst the air was kept stirred the students were much less affected by the oppressive atmosphere. They begged for the fans to be put on when they were cut off. The same stale air containing 3 to 4 per cent. CO_2 , and 16 to 17 per cent. O_2 , was whirled, but the movement of the air gave great relief, because the air was 80° to 85° F. (wet bulb), while the air enmeshed in their clothes in contact with their skin was 98° to 99° F. (wet-bulb). The whirling away of this stationary air cooled the body effectually, for air can hold considerably more water vapour at 98° to 99° than at 80° to 85° . (If the wet-bulb in the chamber registered 99° F., whirling the air would have given little relief.)

The air of the chamber breathed by other students outside caused no discomfort, whereas a student inside breathing the outside air felt no relief.

The pulse frequency was diminished in each case by putting on the fans, and the discomfort relieved.

In other experiments the subject breathed through a very sensitive meter fitted with a mouthpiece, an inlet and an outlet valve. A soda-lime tin, to absorb CO_2 , was at times interposed between the inlet and the mouth. The effect on the respiratory ventilation and on the pulse rate was recorded both when resting and when working. The work consisted in pulling up a 20 kilogram weight about 1 metre high by means of a pulley and rope.

In many of the experiments CO_2 was put into the chamber from a bag full of gas. The subjects inside could not tell when the gas was introduced, not even if the percentage was suddenly raised to 2.

The introduction of this amount of the gas made no sensible difference to them. The subjects wore only a vest, pants and shoes in most of these experiments. When they wore their ordinary clothing the effect on the frequency of the pulse was more marked, and the discomfort from heat and moisture much greater.

In every one of the experiments the putting on of the fans gave great relief. The measured quantity of work was then done with less acceleration of the pulse rate. The refreshing effect of the moving air acting on the skin was very great, but this could not be measured and recorded in figures.

Heat stagnation is, therefore, the cause of the discomfort, and the symptoms arising in the so-called vitiated atmosphere of crowded rooms are dependent on heat stagnation. The moisture, stillness, and warmth of the atmosphere are responsible for the

effects, and the efforts of the heating and ventilating engineer should therefore be directed towards cooling the air in crowded places, and cooling the bodies of the people by setting the air in motion by means of fans. The strain on the heat-regulating mechanism tells on the heart. The pulse is accelerated, the blood is sent in increased volume to the skin and circulates there in far greater volume, while we must assume that less goes through the viscera and brain. The observations of Hewlett show that the velocity of blood-flow in the arm may be increased three to eight times when the subject is in a hot atmosphere, while cooling the atmosphere may reduce it to one quarter the velocity which pertains in normal conditions.* In a hot moist atmosphere the surface temperature rises, the cutaneous vessels dilate, the veins become filled, the arteries may become small in volume and the blood pressure low, the heart is fatigued by the extra work thrown upon it. The influence of the heat stagnation is shown by the great acceleration of the pulse when work is done, and the slower rate at which the pulse returns to its former rate on resting.

The increased percentage of carbonic acid and the diminution of oxygen which have been found to exist in badly ventilated churches, schools, theatres and barracks, are such that they can have no effect upon the incidence of respiratory disease and the higher death rate which statistical evidence has shown to exist among persons living in crowded and unventilated rooms. The conditions of temperature, moisture, and windless atmosphere in such places primarily diminish the heat loss, and secondarily the activity of the occupants, as also the total volume of air breathed, oxygen taken in, and food eaten. The whole metabolism of the body is thus run at a lower plane, and the nervous system and tone of the body are unstimulated by the monotonous, warm, and motionless air. At the same time, the number of pathogenic organisms—saliva spray infection—is increased in such localities, and the two conditions run together—diminished immunity and increased mass influence of infecting bacteria.

Another point of great importance in connection with a warm confined atmosphere is its effect upon the mucous membrane of the nose. This has been clearly demonstrated by F. F. Muecke in conjunction with the writer.†

Under normal conditions when a person comes in from cool surroundings, a cool atmosphere, or the outside air, the mucous membrane is shrunk; it is taut. If touched with a probe it does not pit, it is not congested, and there is very scanty secretion. The effect of going into a heated chamber where the air is at a temperature of about 80° F. and the wet bulb not much lower, conditions such as exist in crowded places, meeting houses, or ballrooms, is that the mucous membrane of the nose becomes turgid with blood and covered with a very thick secretion, while the tissues are swollen. A probe pushed into the tissues forms a pit showing how boggy they are. The airway is so diminished that a person with a spur or any kind of obstruction cannot breathe through the nose when in these hot conditions. The effect of

* *Amer. Journ. of Med. Sci.*, C. xv, p. 656, 1913.

† *Lancet*, May 10th, 1913.

putting on a fan in a hot room and whirling round the same air is to lessen the obstruction of the air channels. Going out into the open air for a few minutes, especially cool open air, causes the blood vessels to contract, but one still finds that the mucous membrane is boggy, that it pits, and that there is a great deal of thick secretion upon it. Thus, when a person goes into warm, moist places the mucous membrane becomes greatly swollen; there is a great deal of tissue lymph in it, a great deal of thick secretion; the exhaled bacteria that are thrown in masses on it are caught in the thick secretion. Then on coming out into the cold again the blood vessels shrink up so that heat should not be lost from the body, and the nasal mucous membrane is left containing thick secretion and a great deal of tissue lymph, a medium for the growth of bacteria, while it loses the blood that defends it from infection. When the mucous membrane is kept taut, as in cool air, the flow of blood is rapid, the inhaled air is warmed up quickly and moisture evaporates from the nose so as to saturate this air at body temperature; more plasma comes out of the blood vessels, and this contains the immunising substances. The ciliated cells are well supplied with plasma, and they lash well, and the offensive bacteria are kept out. But in the condition where there is much secretion and boggy tissues and the blood has been shrunk out by vaso-constriction then there is a suitable nidus for bacteria to grow in.

In many buildings the ventilation system is such that the feet are cooled more than the head. The draught on the feet causes swelling of the nose, feeling of "stuffy head," and obstruction of the air way. Methods of heating and ventilation should be contrived so as to secure warm feet and cool heads, the conditions which pertain out of doors on pleasant days.

THE KATATHERMOMETER.

The experiments in the confined chamber with and without the fan show how the thermometer fails to demonstrate the conditions which we feel. It is no use to trust to the ordinary thermometer, either wet or dry, because it does not show heat loss. It only shows its own temperature, the average temperature of the furniture and surroundings and walls; it does not show the heat loss of the body. While the thermometer is a static instrument indicating average temperature, the human body is a dynamic structure continually producing and losing heat, while its temperature remains sensibly constant. To secure comfortable and healthy conditions of atmosphere in our rooms we require an instrument which indicates not average temperature but rate of cooling.

The writer has therefore contrived an instrument for showing the rate of heat loss—the Katathermometer. It consists essentially of a large-bulbed spirit thermometer graduated from 110° F. to 90° F. with distinctive marks on the stem at 110°, 100°, and 90°. (See Fig. I. opposite.)

Two such instruments are generally employed—one with the bulb uncovered, the dry katathermometer—the other with the

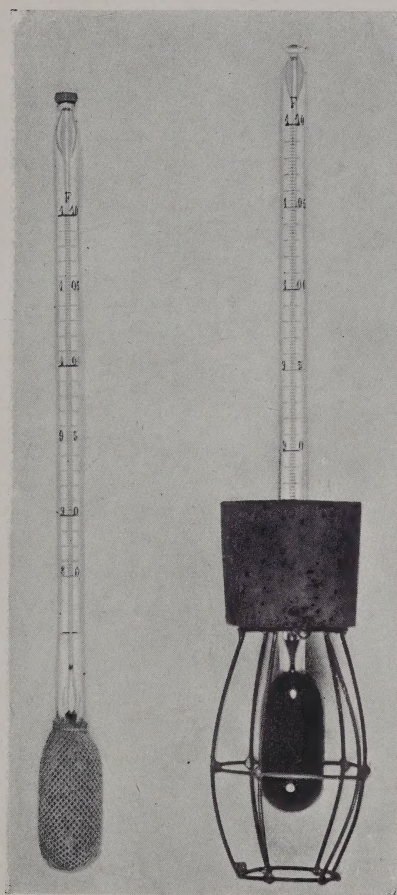


FIG. I.

THE WET AND DRY KATATHERMOMETER.

The Dry instrument is shown enclosed in a wire cage, which is used for taking observations between the skin and the shirt.

bulb covered by a fine cotton mesh—the finger of a lady's thin glove. To employ the instrument the bulbs are immersed in water at about 150° F. until the spirit rises into the small bulb at the top of the instruments. The excess of water is then jerked off the wet bulb, and the other dried. The instruments are then suspended in air, and the rate of cooling from 110° – 100° , and from 100° – 90° taken with a stop watch. The wet bulb loses heat by evaporation—the dry one by radiation and convection.

The instrument has been graduated by taking many observations under a great variety of conditions, both indoor and outdoor. (See Tables II., V.-X.). The readings obtained in conditions which appear to the sensations as ideal have been taken as the empirical graduation of the instrument. Such indoor readings in particular give the standard to be aimed at in the heating and ventilation of buildings.

For example, in Table II., reading 40 shows that on an ideal summer day the outdoor reading (110° – 100°) was 25 sec. for the wet bulb and 85 sec. for the dry bulb katathermometer. Indoors at the seaside in the summer on an ideal day, under pleasant and comfortable conditions, the readings were 50 secs. and 140 secs. respectively.

In the hot chamber it will be seen from the following table (Table I.), that the readings were much longer, denoting heat stagnation in the body.

TABLE I.
KATATHERMOMETER READINGS IN HOT CHAMBER.

Fan.	Wet Kata. 110–100. Time in secs.	Wet Kata. 100–90. Time in secs.	Dry Kata. 110–100. Time in secs.	Dry Kata. 100–90. Time in secs.	Wet Bulb.	Dry Bulb.
Off	—	172	—	870	80	90
Off	—	141	—	520	80	90
On	—	65	—	380	75	90
Nearer Fan.	—	42	—	323	75	90
On	—	80	—	212	72	$79\frac{1}{2}$
Off	—	121	—	383	72	79
On	—	82	—	197	73	80
Off	—	135	—	420	77	84
On	—	83	—	219	$73\frac{1}{2}$	81
Off	92	—	412	—	81	96
On	53	—	279	—	82	99
Off	132	—	676	—	87	100
On	60	—	462	—	87	103
On	66	—	300	—	81	101·5
Off	115	—	508	—	83·5	103
Off	146	—	680	—	85	91·5
On	95	—	482	—	82	94

The great value of the fan in relieving such heat stagnation is no less clearly seen in this table, although the wet and dry bulb thermometers indicated by themselves little or no change in the conditions.

The readings of the katathermometer under these conditions agree with the sensations of any one enclosed in the chamber. (See also Table V.)

TABLE II.

DESCRIPTION OF DAY.	PLACE.	KATATHERMOMETER.				THERMOMETER.		REMARKS.
		Wet.		Dry.		Wet Bulb.	Dry Bulb.	
		110-100	100-90	110-100	100-90			
(1) Spring-like sunny day, fair westerly breeze.	Roof L.H.M.C.	20	27	46	66	49	53	Breeze and sun.
(2) " "	"	21	29	50	69	50	54	Sun warmer, little breeze.
(3) " "	"	19	27	38	47	49	53	Shaded from sun, fair breeze.
(4) " "	"	21	29	55	73	50	54	Sun warmer, practically no breeze.
(5) " "	Indoors.	42	54	116	159	57	62	Window open, gas-fire on.
(6) Fine, cold, sunny day, fair breeze, windy at times.	Roof L.H.M.C.	17	22	36	42	34	37	Windy.
(7) " "	"	20	22	38	45	34	37	Calmer.
(8) Moist, misty, fine calm October morning, chilly.	Loughton.	37	46	79	106	57	57½	9 a.m.
(9) Moist, misty October day, no wind, calm.	"	37	45	88	117	54	54½	Next day to (8), unpleasant.
(10) Same day later	"	40	59	96	131	56½	56½	More pleasant.
(11) Moist, misty, October day ...	"	45	61	128	154	56	57½	—
(12) Cold, misty, windless October day.	"	32	36	80	87	47	47	9 a.m.
(13) Bright, sunny, cool November day.	"	26	—	68	—	46	49½	Head level, } Rate of cooling at 2 p.m. ground less than at head level.
(14) " "	"	35	—	88	—	46	50	Ground level }
(15) Fine, frosty, misty December morning. Sun shining.	"	31	—	69	—	36	—	Head level ... }
(16) " "	"	37	—	80	—	33	—	Ground level }
(17) Mild, spring day. Showery ...	Loughton, Outdoors, 9 a.m.	—	48	—	97	—	62	End of shower, some breeze.
(18) " "	Indoors.	—	68	—	113	—	—	No fire, damp feeling.
(19) " "	Outdoors	—	56	—	120	—	—	No wind, steaming almost, sun veiled.

(20)	"	"	"	48	102	—	—	—	More breeze.
(21)	"	"	"	48	112	—	—	—	Sun out, breeze at times.
(22)	"	"	"	40	105	—	—	—	Sun in, breeze at times.
(23)	"	"	"	45	146	—	—	—	Sun out more or less strongly. Variable breeze. Ideal.
(24)	"	"	"	75	192	—	—	—	Fire, door and window open.
(25)	Bright, sunny summer day	Indoors.	26	61	64	61	61	64	{ Same day.
(26)	"	On cliff, seaside.	45	127	71½	65	65	71½	{
(27)	Cloudy summer day, gentle breeze.	On cliff, seaside.	26	57	62	60	60	62	{
(28)	Sunny, warm day, gentle breeze.	London.	37	112	70	63	63	70	{
(29)	Overcast summer day, strong N.E. wind.	On cliff, seaside.	19	32	60	58	58	60	{
(30)	Overcast summer day, cold breeze.	London.	24	53	59	54	54	59	{
(31)	Close, calm, dry, cloudy summer day.	Seaside.	36	150	67	65	65	67	{
(32)	Close, calm, dry, cloudy summer day. Wind springing up.	"	24	57	—	—	—	—	{
(33)	September day. Fine, sunny at times.	Loughton.	41	100	57	62	62	57	Shade, back of house.
(34)	"	"	37	105	68	63	63	68	Sun veiled, front of house.
(35)	"	"	37	130	72	64	64	72	Sun full out, front of house.
(36)	Fine May day. Sun in and out, cool wind.	Roof, L.H.M.C.	—	66	59	50	50	59	Sun out.
(37)	"	"	—	62	56	47	47	56	Sun in.
(38)	"	"	—	82	56	47	47	56	Sun in, shielded from wind.
(39)	"	"	—	83	59	50	50	59	Sun out, less wind.
(40)	Ideal summer day, sun and breeze.	N. E. Ireland, outdoors.	25	85	—	—	—	—	—
(41)	"	Spinning shed.	76	213	85	84	84	85	Engine going.
(42)	"	"	72	302	88	82½	82½	88	Engine stopped.
(43)	"	"	71	266	—	—	—	—	2 yds. from spindles.
(44)	"	"	53	226	—	—	—	—	9 ins. from spindles.
(45)	Ideal sunny summer afternoon.	"	47	193	82	76½	76½	82	In stand near hygrometer, sunny side.
(46)	"	"	44	149	82	76½	76½	82	In stand near hygrometer, shady side.
(47)	"	"	42	158	82	76½	76½	82	Near moving wheels.
(48)	"	"	66	203	82	76½	76½	82	Central walk, far end from door.

DESCRIPTION OF DAY.	PLACE.	KATATHERMOMETER.				THERMOMETER.		REMARKS.
		Wet.		Dry.		Wet Bulb.	Dry Bulb.	
		110-100	100-90	110-100	100-90			
(49) Ideal sunny summer afternoon.	Spinning shed.	36	—	146	—	76.5	82	Central walk, door end near driving wheel.
(50) "	"	52	—	159	—	76.5	82	Door end, shady side, open window, above hot water troughs.
(51) April day ...	Indoors.	—	95	—	365	73 (middle of room)	75	{ Gas Fire. { Average temperature of walls, 75° D.B. Head temperature, 74° D.B. Floor temperature, 86½° D.B.
(52) "	"	—	79	(Screened)	220	73	75	
(53) "	"	—	90	—	277	73	75	{ Average temperature of walls, 74° D.B. Temperature, head level, 75° D.B.
(54) "	"	—	93	(Screened)	229	73	75	
(55) Fine April day ...	"	—	79	—	275	71	73	{ Floor temperature, 73½° D.B. Average temperature of walls, 73°
(56) "	"	—	79	(Screened)	260	71	73	
(57) "	"	—	81	—	437	72	74	{ Temperature head level, 74° Floor temperature, 72° Average temperature of walls, 74°
(58) "	"	—	74	(Screened)	240	72	74	
(59) February, strong South-west wind.	In Gymnasium, Woolwich Barracks.	45	—	97	—	—	59	{ Fire. { Temperature, head level, 74° Floor temperature, 77½° Windows shut, louvres in roof open.
(60) "	"	23	—	83	—	—	59	Squad of men running and stirring air. All windows open wide. In wind.
(61) "	"	28	—	70	—	—	53	
(62) "	Out of doors in exercise ground.	15	—	25	—	—	51	

The above table (II.) further illustrates many conditions of which the wet and dry bulb thermometer readings in themselves give little or no indication. For example, on a calm and on a windy day the wet and dry bulb thermometer readings may be approximately the same, although the heat loss from the human body under such conditions would be quite different. The kathermometer readings (*e.g.*, readings 31 and 32), reveal this fact.

The readings (25-32) taken on the same day in London and at the East Coast reveal the much greater amount of air movement which there is at the sea. The wet and dry bulb thermometers do not afford much indication of the bracing effects felt by the person at the seaside.

It will be seen also that the katathermometer reveals the fact that the air just above the ground generally cools the body less than the air at head level (*e.g.*, Readings 13-16). This is because the ground is generally warmer than the air, and owing to friction there is little air movement near the ground. The natural ideal conditions out of doors are warm feet and the head cooled by the breeze.

The nature of the heat, whether radiant or convected, is also a matter of great importance. With the help of the katathermometers the writer and Martin Flack have studied the conditions in a small room alternately heated with an anthracite stove and with a gas fire. The anthracite stove gave off the heat of the coal burned, approximately, 10 per cent. as radiant heat, 50 per cent. as convection heat, and 40 per cent. as flue heat. The gas fire used by us gave off 41·7 per cent. as radiant heat, 29·7 per cent. as convection heat, and 28·6 per cent. as flue heat. The latest pattern of gas fire gives off no less than 52·1 per cent. as radiant heat, 23·4 per cent. as convection heat, and 24·5 per cent. as flue heat. These figures were determined for us by Mr. James Yates with an apparatus specially designed for the purpose, and adopted by the Leeds Joint Committee, which considered the measurement of radiant heat given off by stoves. The results obtained show that with the gas fire there is in different parts of the room less uniformity of the rate of heat loss; that the feet and legs are warmed by the radiant heat, while the head is cooler; that one side of the body is warmed by the radiant heat, while the other side is cool; and that the radiant heat provokes sweating. On the other hand, the convected heat tends to make the air at head-level warmer than at the foot-level, and swells up the mucous membrane of the nose, and so causes the stuffy feelings of which people complain in close rooms. Readings 51-58 in Table II. give examples of screening the radiant heat from the katathermometers.

The heat stagnation, which results from a high wet-bulb temperature and motionless air, has been shown in Table I. The same effect is shown by observations taken in certain flax-spinning mills and weaving sheds in the North of Ireland. (Readings No. 40-50, Table II.) It will be seen that the movements of the machinery appreciably affect the ventilation as shown by the kata-

thermometer readings, although the hygrometer hanging in the middle way gives no indication of this fact. The spinner, who is moving to and fro close to the moving spindles, is cooled by the draught from these, and the conditions become much more oppressive when the machinery stops:

THE EFFECTS OF THE TEMPERATURE AND MOVEMENT OF AIR UPON THE SKIN-SHIRT TEMPERATURE.

The effect of the temperature and movement of the surrounding air upon the temperature of the air between the skin and shirt have been investigated by means of the ordinary wet and dry bulb thermometers and also by the wet and dry katathermometers.

Thermometer readings taken with the individual sitting quiet are shown in Table VI., cols. 7 and 8. It will be seen that the skin temperature on a windy day may be as low as 64° F. wet bulb, 74° F. dry bulb. Temperatures considerably lower than this are obtained when the individual himself is in rapid motion, as for example, bicycling quickly down hill into the wind. This is well exemplified by the following table:—

TABLE III.

Day.	Skin-Shirt Temperature.		Remarks.
	Wet Bulb. °F.	Dry Bulb. °F.	
Winter day, warm day for cycling. W. B. 42, D. B. 45.	74	82	Sweating after cycling up hill.
“ “ “	64	68	After cycling down hill.
“ “ “	76	82	In room with fire. W. B. 59, D. B. 65.
Hard, frosty, clear day W. B. 31, D. B. 28.	50	59	After cycling down hill.
Cold, clear frosty day. W. B. 31, D. B. 31.	48	58	After cycling down hill.
Frosty calm day. W. B. 31, D. B. 30.	61	68	After cycling up hill.
“ “ “	52	58	After cycling down hill.

The temperatures were taken with delicate thermometers carried in pairs (wet and dry) in a specially devised brass case and so arranged that the surface of the skin was not touched by the bulbs which lay between the skin and the shirt or vest.

In Tables VII.-X. many readings of the katathermometers are given under various conditions. It will be seen that the skin-shirt katathermometer readings vary greatly. In taking these temperatures the bulbs of the katathermometers were prevented from touching the skin by being enclosed in wire cages (see illustration). Readings tend to show that these vary more according to

the amount of wind than according to the actual temperature of the surrounding air. This is particularly the case when the amount of clothing is not large. The wet bulb katathermometer readings were taken from 110-100 and the dry from 110-105. The indoor skin-shirt katathermometer readings vary considerably with different individuals and the conditions (room, temperature, clothing, etc.). From tables VIII.-X. it will be seen that average readings are, wet 80-120, dry 150-200.

Outdoors with a good wind these readings may be as short as: wet (110-100) 39, dry (110-105) 34. This is in summer at the seaside when the subject has a cotton shirt and an open coat on.

The following readings have been noted upon workers in hot moist flax-spinning sheds:—

TABLE IV.

“SKIN-SHIRT” RATE OF COOLING AS SHOWN BY KATA-THERMOMETERS IN WARM WEAVING SHEDS.

Subject.			W. K. 110-100.	D. K. 110-105.	Remarks.
L. H.	...	...	51	255	Room, Wet Bulb, 71. Dry Bulb, 82. ,, Wet Kata, 56. Dry Kata, 215. (110-100). (110-100).
Male (overlooker)...			51	230	Vest, shirt, waistcoat.
			70	240	
Child	...	...	51	267	Cotton dress and thin cotton shirt.
Male	...	...	45	265	Mill. Wet Bulb, 71.5. Dry Bulb, 78.5. ,, Wet Kata, 48. Dry Kata, 180 (110-100). (110-100).
					Shirt, waistcoat, cotton coat.
Girl	...	...	39	179	Cotton blouse wide open, bare feet.

By their bare feet and legs and open necks the young workers must compensate for the conditions indicated by the high skin-shirt readings. A suitable kind of garment such as worn in the tropics would improve the comfort of these workers.

To compare with these we give some figures obtained in the experimental chamber warmed to a high wet bulb temperature. It will be seen that when only a cotton shirt is worn, putting on the fan increases the rate of cooling of the “skin-shirt” air by 100 per cent. or more, depending upon proximity to fan, whereas when more than one garment is worn, *e.g.*, a closely-woven vest and waistcoat, the rate of cooling is not increased to the same extent.

TABLE V.

Skin-Shirt.		Chamber.			Remarks.
Wet Kata. 110-100.	Dry Kata. 110-100.	Dry Kata. 110-105.	Wet Bulb.	Dry Bulb.	
274	912	—	88	92	Fan off. Readings taken under cotton shirt only.
149	465	—	86	93·5	Fan on, 2 ft. 6 in. from subject. Under cotton shirt.
133	752	—	85	95	Fan on. Under cotton shirt and linen jacket.
150	962	303	83	95	Fan off. Under thick Jaeger vest
95	482	180	82	94	Fan on. Under thick Jaeger vest.
229	855	—	83	95	Fan off. Much sweating. Under sweater with fairly large mesh.
84	454	—	83	96	Fan on. Under same garment. No sweating.
140	970	—	82·5	96	Fan off. Under cellular cotton shirt and vest. Sweating.
84	545	—	81·5	96	Fan on. Under same clothes. No sweating.
217	963	290	83·5	104	Fan on. Under closely woven vest and waistcoat.
166	635	236	83·5	104	Chest held closer to fan.
158	—	232	87	100	Fan off. Sweating. Under cotton shirt.
82	—	198	87	105	Fan on. Chest close to fan. No sweating.
90	600	197	82·5	95	Fan on. No sweating. Under vest only.
135	616	208	81·5	94·5	Under vest and white linen shirt.
152	650	202	82·5	93	Under vest and shirt and waistcoat.

THE EFFECTS OF THE TEMPERATURE AND MOVEMENT OF THE SURROUNDING AIR UPON METABOLISM.

The effect upon metabolism has been studied upon the principle of the method recently described by Douglas,* except that a much bigger bag has been used.† The procedure is as follows:—

The subject sits comfortably at ease and by means of a tube and inspiratory valve breathes in the surrounding air while the expired air is collected by means of an expiratory valve and tube in a large rubber bag of about 400-600 litres capacity. This bag is placed behind the subject so that its gradually increasing volume in no way attracts his attention and he is unaware whether he is breathing more or less than in any previous experiment. A nose clip is worn to prevent the possibility of any unconscious expiration by that channel. The experiment has generally been pursued

* C. Gordon Douglas, Proc. Physiol. Soc. : *Journ. Physiol.*, XLII, xvii, 1911.

† Such bags were kindly furnished by Messrs. Siebe, Gorman and Co., Westminster Bridge Road, who also supply Douglas's apparatus.

for thirty minutes; in the meantime the wet and dry bulb temperature of the atmosphere, the rate of pulse, and often the rate of respiration being noted. In most cases also the "skin-shirt" temperature has been taken at intervals by ordinary thermometers or rate of cooling by katathermometers. At the end of thirty minutes the expiratory tube is clamped with large forceps, the contents of the bag well mixed by thoroughly shaking it—and the contained air then measured by carefully forcing through an Elster (Berlin) meter such as is used by Zuntz in his experiments on metabolism. During this process two or more samples of the air are taken from a side tube into vacuum sampling tubes. The samples have been analysed by Haldane's gas analysis apparatus, and the results give the average composition of the air expired during the experimental period of thirty minutes. In this way is obtained, as the following tables show, the total amount breathed in thirty minutes, and the composition of the expired air, and from this may be calculated the amount per minute of O_2 taken into the body and of carbon dioxide given out from the body. In calculating the oxygen used we have taken the percentage of oxygen in the atmosphere as 20.80 per cent., the figure obtained by us in analysis at room temperature. As all the results are comparative of indoor and outdoor effects on one and the same day, we have not reduced the figures to $0^\circ C.$ and 760 mm. Hg. The room temperature at which the analyses were made varied but little from day to day while the variation in the physiological results obtained under the different conditions are very large, so that the results obtained on different days are comparable. As the temperature of the expired air collected and measured outside was usually lower the error lessens the striking increase in metabolism which we have obtained.

Table VI. gives the effect of open air upon the metabolism of one subject—Dr. Martin Flack. With the exception of the four indoor observations taken to get an idea of the rate of metabolism at an equable indoor temperature, all observations were taken on the roof of the London Hospital Medical College. The same amount of clothing was worn on all occasions and the experiments were made at the same hour of the day—being about twelve noon—three and a half hours after breakfast. The breakfast was kept of about the same character. It will be seen that most varied weather was experienced.

TABLE VI.

Subject M. F. Date.	Amount breathed for 30 minutes.	Expired Air.		Amount of CO ₂ expired per min.	Amount of O ₂ absorbed per min.	Skin-Shirt Thermometer.		Wet Bulb.	Dry Bulb.	Pulse.	Remarks.
		CO ₂ per cent.	O ₂ per cent.			Wet Bulb. ° F.	Dry Bulb. ° F.				
1913. Feb. 4	259	3.99	15.17	344.47	456.1	82	84	53 sun. 51 55 shade.	57 sun. 58 55½ shade.	—	<i>Outdoors</i> —Sun shining, good wind blowing.
4 7	301 295	3.51 4.13	16.25 14.77	352.2 406.1	456.5 592.9	88 74	90 77	54 51½	58 53½	72 66	<i>Indoors</i> —Working, not sitting quiet. <i>Outdoors</i> —Dull, overcast and very windy. Hands and legs cold.
11	234	4.11	15.7	320.6	397.8	88	92	43	44	72	<i>Outdoors</i> —No wind, foggy, very still.
13	310	4.08	15.79	421.7	517.7	81	85	40½	41	66	<i>Outdoors</i> —Cold day, slight mist, fair breeze. Hands got cold.
14	281	3.79	16.04	355.0	445.9	85	86	39	40	76	<i>Outdoors</i> —No sun and occasional slight breeze. Not so cold to senses.
17	310	3.90	15.91	403.1	505.4	74	79	41	43	72	<i>Outdoors</i> —Fair breeze at times, clear, dry, day. Hands and feet coldish.
18	324	4.09	15.49	441.7	573.5	72	79	37	40	66 70 av. 66 calm. 76 wind blowing.	<i>Outdoors</i> —Sunny, strong wind, gusty at times. Hands and feet cold.
19	305	4.29	14.99	436.2	590.7	72	79	36	40	72 76 in wind. 66 calm.	<i>Outdoors</i> —Sunny, strong wind most constant. Hands and feet cold, rest- less at end.
20	311	4.17	15.36	432.3	564.0	79	85	31½	35½	72	<i>Outdoors</i> —Good breeze, not gusty. Over- cast. Hands and feet cold.
21	273	4.16	15.01	378.6	527.0	78	89	39½	45	76 70	<i>Outdoors</i> —Pleasant wind, strong at times. Got cold towards end.

24	236	4:07	15:33	320.2	430.3	86	92	43	50	80	Outdoors—Sunny, nice breeze. "Dozed in sunshine."
25	218	4:15	15:9	301.6	364.4	81	87	43	49	78	Outdoors—Dull, with gentle breeze. Kept very quiet and comfortable.
26	240	4:02	15:72	321.6	406.4	88	93	47½	52	68	Outdoors—Dull, scarcely any breeze. Comfortable.
27	248	4:01	15:50	331.5	438.2	81	90	45	52	—	Outdoors—Overcast, fair-strong breeze and sun at times.
Mar. 3	266	4:20	15:26	372.4	491.2	79	90	50	53	84	Outdoors—Dull, gusty west wind, not cold.
4	273	4:33	14:70	394.1	555.1	76	84	50	53	78	Outdoors—Dull, strong wind, westerly. in wind.
5	245	4:05	15:99	330.9	392.8	81	90	49	59	76	Outdoors—Gentle breeze. Ideal day.
10	245	4:12	15:74	336.5	413.3	78	88	49	50	72	Outdoors—Dull, overcast, drizzle at times, good gentle breeze at times.
11	236	4:44	15:56	349.3	412.2	76	86	48	52½	72	Outdoors—Dull, good breeze at times.
13	260	4:05	16:00	351.1	416.0	81	88	47	51	68	Outdoors—No breeze. Trace of mist.
17	363	4:32	15:45	522.8	647.4	64	74	36½	38½	78	Outdoors—Cold wind blowing hard all times, snow and sleet at beginning, then snow. Got cold and shivered a lot.
18	255	4:29	15:87	364.7	419.0	80	84	35	39½	72	Outdoors—Pleasant cold day, mist. No breeze.
19	338	4:49	15:50	505.8	597.1	69	77	42½	44 going to	84	Outdoors—Strong wind blowing, gusty at times. Raining at first, then sun.
May 13	245	3:57	16:06	288.3	387.2	83	88	45	53	92	Outdoors—Beautiful warm, sunny day, gentle breeze at times.
1914.						Dry Kata. 110-105	Wet Kata. 110-100				
Feb. 9	183	4:29	15:43	261.6	327.9	177	92	55	60	70	Indoors—Gas fire on. Sitting very quiet reading.
10	227	3:50	15:90	264.8	370.7	179	121	54	59	76	Indoors—Gas fire on. Sitting writing.
11	200	3:99	15:81	266.0	332.6	178	108	55	59	72	Indoors—Gas fire on. Sitting writing.

Table VII. shows the effect of open air under similar conditions upon two other subjects during the months of May, June, and July. The experiments were also made on the roof of the London Hospital Medical College. In this table katathermometer readings are given of the atmosphere, the skin-shirt temperature being taken with the ordinary thermometer.

TABLE VII.

Subject.	Amount breathed in 30 minutes.	Analysis of expired air.		Amount of CO ₂ expired per min.	Amount of O ₂ absorbed per min.	Skin-Shirt thermometer.		Pulse.	Kata- thermometer reading.		Thermometer.		Remarks.
		CO ₂ per cent.	O ₂ per cent.			Wet Bulb. °F.	Dry Bulb. °F.		Wet 100-90. in secs.	Dry 100-90. in secs.	Wet Bulb. °F.	Dry Bulb. °F.	
H. B. W.	282	3.75	16.24	352.5	428.6	86	91	72	45	255	68	83	<i>Outdoors</i> —On roof. Bright sunny May day, gentle breeze, overcast at times.
"	278	3.97	16.23	367.9	423.5	80	89	74	37	144	58	70	<i>Outdoors</i> —Bright sunny day, gentle breeze.
"	298	3.58	16.07	355.6	469.9	84	88	68	29	65	58	63	<i>Outdoors</i> —Overcast June day, windy, rather coldish.
L. H.	231	4.53	15.55	348.8	404.2	80	90	60	24	73	50	59	<i>Outdoors</i> —Fine May day, sunny at times, gentle to fair breeze.
"	333	3.45	16.91	382.9	431.7	80	86	—	35	195	65½	75	<i>Outdoors</i> —Cloudy fine May day, nice breeze. No coat or waistcoat. Felt nice and cool.
"	320	3.53	16.61	376.5	446.9	79	85	60	24	—	52	61	<i>Outdoors</i> —Fine June day, cool breeze blowing. White coat on.
"	270	4.04	16.28	360.4	406.8	Wet Kata. 110-100	Dry Kata. 110-105	58	23	61	57	63	<i>Outdoors</i> —Cloudy July day, some sun at times, showery, pleasant breeze blowing.
"	236	4.57	15.80	359.5	392.3	77	—	57 55	—	—	53	63	<i>Outdoors</i> —Overcast, quiet July day.

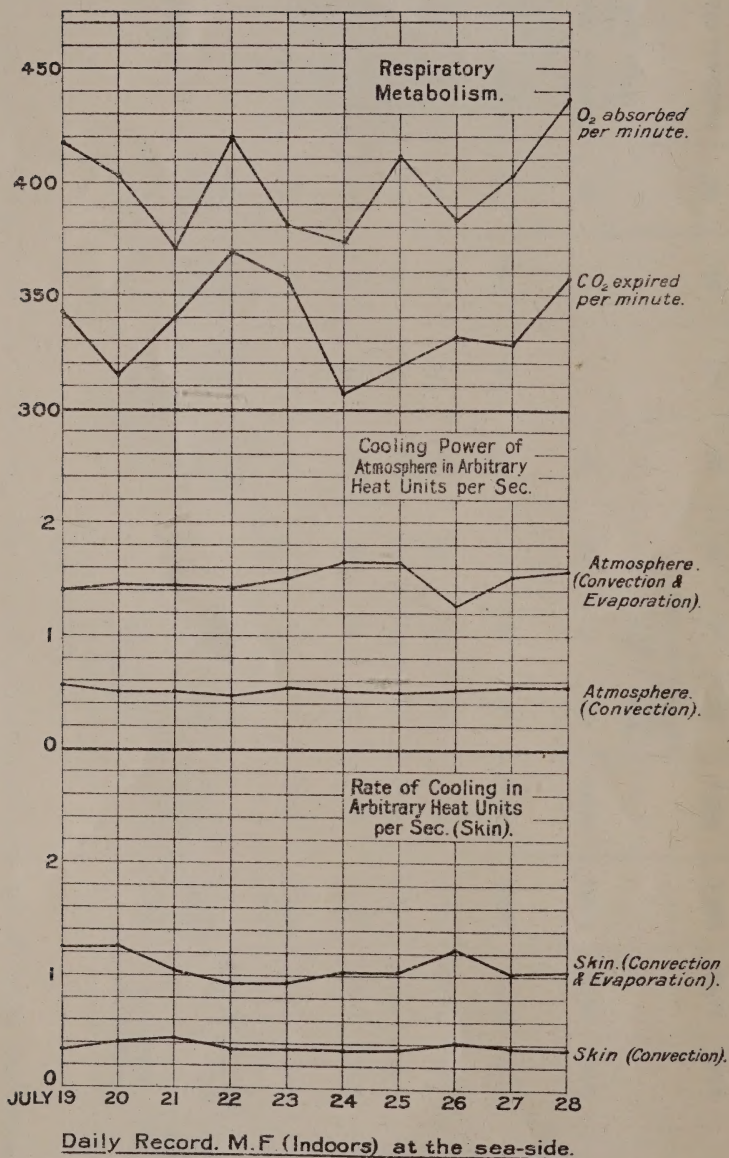
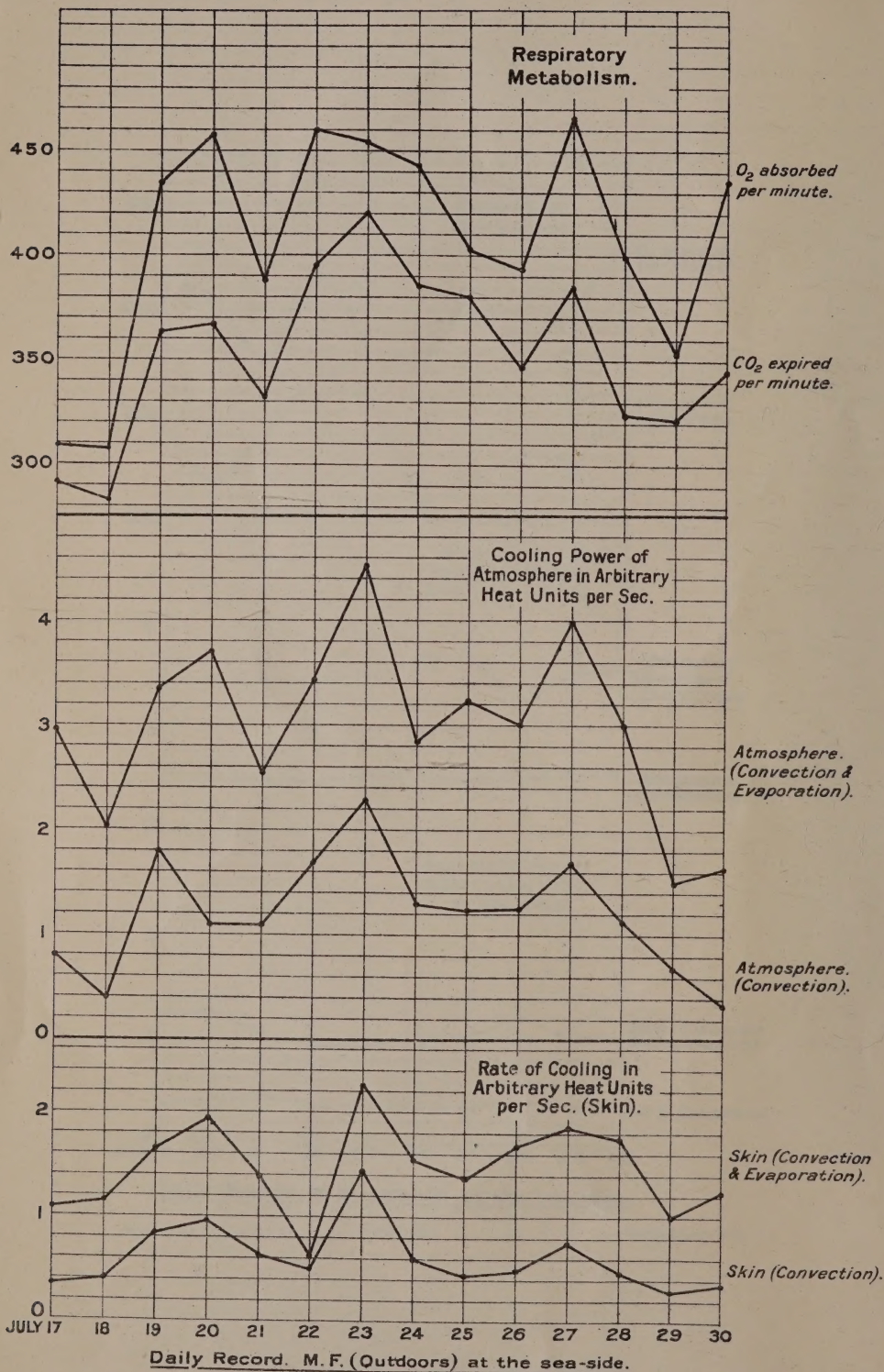
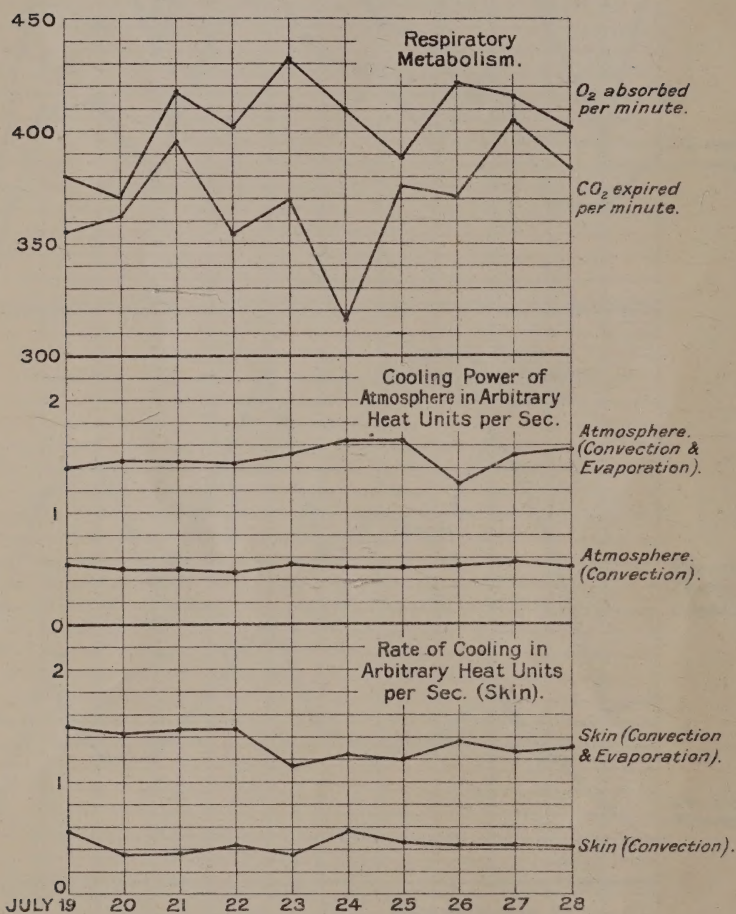


FIG. II.





Daily Record, L. H. (Indoors) at the sea-side.

2858, 47080, 572, 1000, 7, 14.

FIG. IV.

Malby & Sons, Lith.

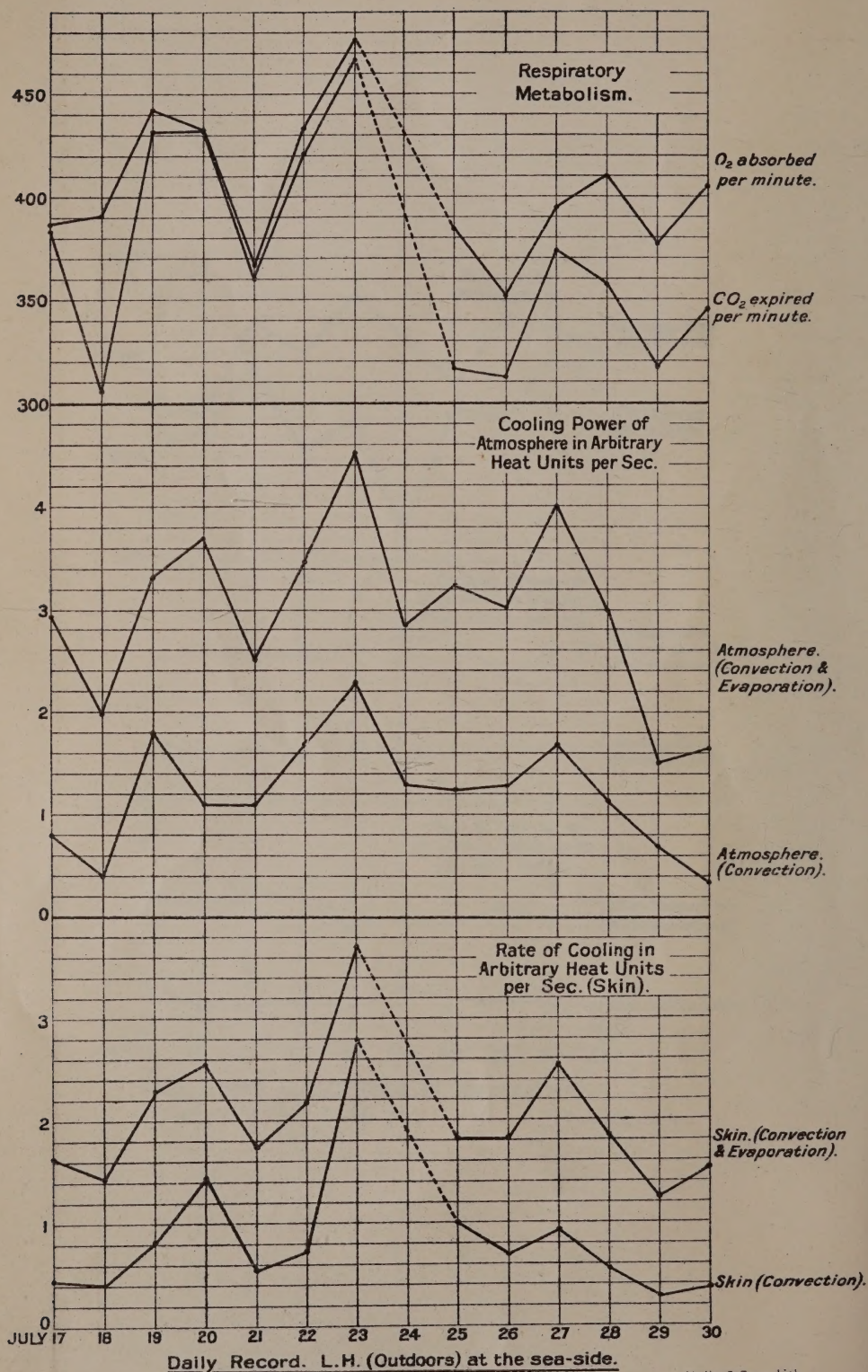


TABLE VIII.

Subject.	Date.	Amount breathed in 30 minutes, in litres.	EXPIRED AIR.		CO ₂ expired per minute.	O ₂ absorbed per minute.	Skin-Shirt Katathermometer.		ATMOSPHERE.				Pulse.	REMARKS.	Subject.	Date.	Amount breathed in 30 minutes, in litres.	CO ₂ per cent.	O ₂ per cent.	CO ₂ per minute.	O ₂ per minute.	Skin-Shirt Katathermometer.		Pulse per minute.		
			CO ₂ per cent.	O ₂ per cent. 20.80.			110-100° Wet in secs.	110-105° Dry. in secs.	Katathermometer.													110-100° Wet in secs.	110-105° Dry in sec.			
									Wet		Dry														Wet Bulb.	Dry Bulb.
									110-100° 100-90° in secs.	Total.	110-100° 100-90° in secs.	Total.														
M. F.	July 17	224	3.91	16.64	291.9	310.6	180 93	226* 150†	$\frac{32}{125}=60$	$\frac{84}{125}=209$	64	69	72	Outdoors on cliff—*Waistcoat shut. †Waistcoat open. Soft, variable breeze west, generally overcast, sun at times. Clothing, excepting this day:—Unbuttoned coat, loose woven shirt, trousers, shoes, no socks. L. H. this clothing every day.	L. H.	July 17	290	3.97	16.80	383.3	386.6	61	115	—		
"	18	241	3.55	16.20	281.8	306.9	86	124	$\frac{30}{125}=78$	$\frac{150}{125}=355$ $\frac{90}{125}=150$	65	67	72	Outdoors—Close, calm, dry, cloudy day. Wind at finish.	"	18	303	3.40	16.94	304.34	389.8	71-66	132-110	54		
"	19	284	3.84	16.20	363.5	435.0	60	59	$\frac{37}{125}=57$	$\frac{48}{125}=95$	53	54	70-72	Outdoors—Coldish, dull day, windy at times ..	"	19	450	2.88	17.85	432.0	442.5	(110-105°) 22, 21	65, 60	55		
"		272	3.77	16.20	341.8	417.7	81	148	$\frac{50}{125}=121$	$\frac{117}{125}=299$	60	62	72	Indoors	"		392	2.72	17.89	355.4	380.2	33	93	51		
"	20	262	3.61	16.29	315.2	402.6	80	122	$\frac{50}{125}=118$	$\frac{138}{125}=337$	61	65	72	Indoors	"	20	363	2.99	17.75	361.7	369.5	(110-105°) 35	133	56		
"		326	3.38	16.58	367.2	458.9	52	52	$\frac{32}{125}=50$	$\frac{59}{125}=139$	57½	65 (sun) in wind. 72 62½	80	Outdoors—Fine, bracing, windy, northerly sunny, overcast at times.	"		472	2.76	18.05	433.2	432.1	(110-100°) 39	34	60-58		
"	21	276	3.70	16.78	340.40	369.84	95	133	$\frac{49}{125}=118$	$\frac{145}{125}=341$	58½	62	72	Indoors	"	21	368	3.23	17.39	396.21	418.29	67	132	64		
"		288	3.46	16.77	332.16	386.88	72	118	$\frac{38}{125}=67$	$\frac{72}{125}=162$	58	62	67	Outdoors—Generally overcast, fine, gentle breeze, at times rather airless.	"		349	3.09	17.67	359.47	364.12	56	93	56		
"	22	256	4.33	15.88	369.49	419.84	104	140	$\frac{51}{125}=121$	$\frac{145}{125}=348$	62	65	75	Indoors	"	22	320	3.32	17.03	354.13	402.13	67	116	56		
"		297	4.00	16.15	396.00	460.35	165	101	$\frac{37}{125}=53$	$\frac{59}{125}=109$	57	59	79	Outdoors—Overcast, windy generally, raining after first five minutes.	"		413	3.05	17.65	419.88	433.65	45	66	57		
"	23	269	3.98	16.56	356.87	380.15	105	142	$\frac{43}{125}=109$	$\frac{131}{125}=313$	58	60	72	Indoors	"	23	326	3.41	16.82	370.55	432.49	86	148	58		
"		301	4.19	16.26	420.39	455.51	44	35	$\frac{30}{125}=42$	$\frac{38}{125}=76$	58	60	80-72	Outdoors—Overcast, gusty, strong north-east wind.	"		517	2.71	18.04	467.35	475.64	27	18	60-62		
"	24	238	3.86	16.08	306.22	374.45	96	147	$\frac{50}{125}=110$	$\frac{136}{125}=335$	60	63	80	Indoors	"	24	292	3.24	17.17	315.36	353.32	79	87	60		
"		323	3.55	16.68	385.21	443.58	65	81	$\frac{38}{125}=61$	$\frac{72}{125}=135$	65	68	78	Outdoors—Fine, sunny, ideal, bracing, fair north-east wind off sea.	"											
"	25	280	3.92	16.38	365.86	412.53	95	137	$\frac{47}{125}=107$	$\frac{141}{125}=338$	60	62½	72	Indoors	"	25	321	3.52	17.17	376.60	388.41	83	105	66		
"		324	3.52	17.03	380.12	403.82	72	110	$\frac{37}{125}=58$	$\frac{87}{125}=137$	60	62½	68	Outdoors—Cloudy, gentle, pleasant breeze off sea.	"		285	3.69	16.76	317.21	383.80	55	46	63-60		
"	26	264	3.77	16.45	331.79	383.13	81	121	$\frac{52}{125}=130$	$\frac{138}{125}=326$	61	63	72	Indoors	"	26	313	3.52	16.80	370.77	421.33	73	113	56		
"		272	3.83	16.46	347.25	393.47	63	102	$\frac{38}{125}=59$	$\frac{78}{125}=142$	58½	60	72	Outdoors—Pleasant, gentle north-east breeze off sea, no sun.	"		290	3.23	17.20	312.23	351.33	55	71	54		
"	27	245	4.04	15.88	329.93	401.80	93	128	$\frac{53}{125}=119$	$\frac{120}{125}=297$	59	61	72	Indoors—Windows shut	"	27	333	3.65	17.04	405.15	417.36	78	108	60		
"		336	3.81	16.16	384.81	468.64	54	65	$\frac{30}{125}=45$	$\frac{77}{125}=102$	57	59	70	Outdoors—Cloudy, cool, gentle breeze	"		295	3.70	16.79	363.83	394.31	38, 40	51	58-56		
"	28	292	3.67	16.31	357.21	437.02	93	132	$\frac{48}{125}=112$	$\frac{127}{125}=307$	59	62	72	Indoors—Windows shut	"	28	312	3.69	16.92	383.76	403.52	76	120	68		
"		266	3.65	16.31	323.63	398.11	57	104	$\frac{38}{125}=59$	$\frac{87}{125}=150$	61	64	72	Outdoors—Bright, sunny, gentle breeze	"		331	3.24	17.07	357.48	411.54	54	84	62-63		
"	29	260	3.71	16.02	321.53	351.86	101	182	$\frac{48}{125}=115$	$\frac{105}{125}=249$	66	69	72	Outdoors—Somewhat overcast, slight mist over sea, gentle breeze at times.	"	29	281	3.41	16.77	317.07	377.47	73, 82	165	68		
"	30	280	3.68	16.20	343.46	429.10	80	132	$\frac{41}{125}=102$	$\frac{167}{125}=452$	61	63	84	Outdoors—Lovely sunny day, no breeze, no clouds. Coats off, shirt undone at collar. Legs and arms bare.	"	30	341	3.05	17.23	346.68	405.79	65	115	63		

Figures II., III., IV., and V. demonstrate the respiratory metabolism and rates of cooling at the seaside in the form of curves.*

Out of doors the greatest metabolism is seen to coincide with the greatest rate of cooling.

The next, Table VIII., gives a series of experiments made on the East Coast in July upon consecutive days and upon two subjects—Dr. Martin Flack and the author. On most days two sets of observations were made, one indoors in a cottage room on the edge of the cliff, the other out of doors upon the edge of the cliff with flat open country behind. Katathermometer readings were taken both in the atmosphere and between the skin and shirt of the subject. As before, the experiments were done at the same time of the day, and except where stated the same amount of clothing (shirt, trousers, coat) were worn.

In Tables IX. and X. are given the results obtained upon various subjects, first indoors and then outdoors. In this case the experiments were again performed in London at the London Hospital Medical College. In Table IX. the amount of clothing worn indoors and outdoors was the same.

In Table X. the subject on first going out of doors was made very comfortable with rugs and hot water bottle, as a patient is when on the balcony of a ward of the London Hospital. An overcoat and gloves were also generally worn. After half-an-hour these comforts were discarded, and the experiment repeated with the subject wearing only the same clothing as indoors.

* I am indebted to Mr. O. W. Griffith (Lecturer on Physics at the London Hospital Medical College) for the working out of these curves.

TABLE IX.

Subject	Amount breathed in 30 minutes. Respiration per min. in brackets.	Analysis of expired air.		CO ₂ expired per minute.	O ₂ absorbed per minute.	Skin-Shirt Kata- thermometer.		Pulse per minute.	Katathermometer.				Wet. Bulb.	Dry. Bulb.	Remarks.
		CO ₂ per cent.	O ₂ per cent.			Wet.			Dry.		Wet. Bulb.	Dry. Bulb.			
						110-100° in secs.	100-90° in secs.		110-100° in secs.	100-90° in secs.					
N	191 (16)	3.76	16.57	239.3	269.3	73	225	70	38=87 44=97	123=272 123=274	49	54	Indoors—Gas fire. Subject used to sleep- ing in open air. Clothing:—medium vest, cotton shirt, waistcoat, coat buttoned.		
	248 (20)	4.15	16.27	343.0	374.48	56	118	64	123=41 23=50	22=82 23=112	34	37	Outdoors—Fine, sunny cold, fair breeze, windy at times, clothing as above.		
N	179 (16) 191 (19)	4.00 3.86	16.30 16.36	238.6 245.7	244.5 282.7	78 74	173 176	70 65	21=82 23=50	122=274 23=112	49 38	53 38½	Indoors—Clothing, etc., as before. Outdoors—Dull, close day. Drizzle at start, gentle breeze at times.		
N	200 (17) 304 (19)	3.95 3.56	16.16 17.00	263.3 360.7	309.3 385.0	72 67	179 100	70 64	44=97 17=36	117=263 21=77	48 32	52 35	Indoors—Clothing, etc., as before. Outdoors—Cold, clear, dullish day, fair breeze, strong at times. Feet got coldish, did not shiver.		
MS	193 (15)	4.29	15.90	275.9	315.2	129	169	66	41=99	123=275	52	55	Indoors—Clothing:—Thin cellular vest, cotton shirt, waistcoat, coat buttoned. Gas fire on.		
	417 (20-36)	3.12	17.44	433.7	476.04	63	116	68-80	25=46	55=113	39 38	41 40	Outdoors—Dull, overcast day, gentle breeze at first, good breeze later. Legs and hands got cold, started to shiver.		
MS	236 (18)	3.48	16.88	273.7	308.3	84	186	73	27=84	104=221	46	49	Indoors—Room little coldish. Clothing, etc., as before.		

	576 (18-56)*	2·70	17·90	518·4	541·4	60	142	72-75	$\frac{43}{43}=\frac{44}{44}$	$\frac{41}{41}=\frac{95}{95}$	33	35	<i>Outdoors</i> —Cold, dull day, fair easterly breeze at times. Shivering much at end. * Conscious increase of ventilation.
GS	160 (18)	4·00	16·15	213·3	248·0	69	178	72	$\frac{27}{27}=\frac{84}{84}$	$\frac{113}{113}=\frac{262}{262}$	41	45½	<i>Indoors</i> —Room little coldish. Clothing :—Thin singlet, cotton shirt, waistcoat, white linen coat.
	332 (22)	3·46	16·69	382·9	454·4	64	138	64	$\frac{35}{35}=\frac{55}{55}$	$\frac{45}{45}=\frac{98}{98}$	34½	37	<i>Outdoors</i> —Clear, dullish day, very gentle easterly breeze at times. Feet cold.
GS	194 (20)*	3·26	17·52	210·8	212·1	82	190	72	$\frac{40}{40}=\frac{90}{90}$	$\frac{124}{124}=\frac{278}{278}$	53	58	<i>Indoors</i> —Clothing as before
	230 (22)	3·66	16·58	280·6	356·9	69	156	60	$\frac{34}{34}=\frac{56}{56}$	$\frac{59}{59}=\frac{119}{119}$	36	38	* Worried somewhat by mouthpiece. <i>Outdoors</i> —Clear, calm day, not so cold to feet as day before. Not so chilled at end of time.
LH	237 (16)	4·21	16·94	332·5	304·9	80	189	62	$\frac{38}{38}=\frac{87}{87}$	$\frac{114}{114}=\frac{263}{263}$	52	56	Jan. 7.— <i>Indoors</i> —Gas fire on. Thin wool vest, cotton shirt, waistcoat, coat unbuttoned.
	284 (24-26)	3·65	16·82	345·5	376·8	60	123	60	$\frac{18}{18}=\frac{39}{39}$	$\frac{32}{32}=\frac{91}{91}$	35	38	<i>Out on roof</i> —Fine frosty cold day. Sun just showing, back turned to gentle westerly breeze.
LH	210 (18)	3·98	15·77	278·6	352·1	113	180	64	$\frac{32}{32}=\frac{89}{89}$	$\frac{128}{128}=\frac{268}{268}$	47	52½	Jan. 12.— <i>Indoors</i> —Gas fire on, window open.
	296 (24)	4·12	15·63	406·5	510·1	68	133	60	$\frac{18}{18}=\frac{39}{39}$	$\frac{42}{42}=\frac{102}{102}$	31	32	<i>On roof</i> —Snowing, very cold to hands, at times gentle wind in gusts. Shivering and hunched up at finish.
LH	225 (18-19)	4·21	15·84	349·08	372·00	—	210	63	$\frac{32}{32}=\frac{93}{93}$	$\frac{125}{125}=\frac{313}{313}$	50	55	Jan. 13.— <i>Indoors</i> —As before.
	296 (21-24)	4·00	15·92	394·6	481·49	60	129	63	$\frac{28}{28}=\frac{47}{47}$	$\frac{42}{42}=\frac{87}{87}$	35	37	<i>On roof</i> —Cold day, cloudy, gentle breeze, bracing, drier and pleasanter than Jan. 12.

S.E.	141 (14)	4.68	15.61	219.96	243.93	115	163	66	$\frac{48}{58}=105$	$\frac{113}{113}=271$	55	60	<i>Indoors</i> —Gas fire on. Quietly reading. White coat, buttoned waistcoat, cotton shirt, cotton vest.
	223 (20)	3.69	16.75	274.29	301.05	62	134	66	$\frac{34}{47}=54$	$\frac{47}{47}=107$	45	47½	<i>Outdoors</i> —Reading. Dullish day, fresh and mild, fair westerly breeze at times. No overcoat or gloves, but two rugs round legs and hot-water bottle to feet. Did not get chilly.
	276 (22)	3.57	16.96	328.45	353.28	40	125	60	$\frac{34}{47}=56$	$\frac{48}{48}=105$	45½	47½	<i>Outdoors</i> —Same as before, but no rugs or hot-water bottle. At finish face looked cold, hands felt cold, legs were cooler. No pants worn.
I.F.	95 (12-14)	5.34	14.57	169.10	197.28	132	232	68	$\frac{42}{42}=96$	$\frac{113}{113}=275$	57	62	<i>Indoors</i> —Gas fire on, window open. Quietly reading. Coat not buttoned, waistcoat, cotton shirt, thick double-fronted vest.
	149 (14)	5.23	15.00	259.75	288.06	78	157	66	$\frac{39}{49}=49$	$\frac{48}{48}=112$	49	53	<i>Outdoors</i> —Fine sunny spring-like day, fair to strong westerly breeze, mild. Overcoat, gloves, rug, hot-water bottle, etc. Quietly reading.
	157 (15)	5.23	15.09	273.70	298.82	76	132	60	$\frac{41}{51}=50$	$\frac{58}{58}=119$	50	54	<i>Outdoors</i> —No overcoat, rugs, hot-water bottle, etc. Sun warmer. Hands chilly at end. Quietly reading all the time.

In Table XI. are summarised the average results obtained from the observations on the respiratory metabolism of eight individuals who sat quiet for successive half hours,* first in a room and then on the roof of the London Hospital Medical College exposed to cold wintry weather. In either case the subjects wore their ordinary indoor clothes.

TABLE XI.
COLD WINTER WEATHER.

Subject.				Pulmonary ventilation per minute, in litres.	CO ₂ output per minute.	O ₂ intake per minute.	Respiratory. quotient.
N. ...	Indoors	...	...	6.3	247	274	.90
	Outdoors	...	...	8.3	316	347	.91
G. S....	Indoors	...	...	5.9	212	230	.92
	Outdoors	...	...	9.4	331	405	.82
M. S.	Indoors	...	...	7.1	275	312	.88
	Outdoors	...	...	16.5	476	504	.94
F. T....	Indoors	...	...	4.7	179	226	.79
	Outdoors	with rugs,					
	etc.	...	...	6.2	234	313	.74
	Outdoors	...	...	7.5	315	364	.86
S. E....	Indoors	...	...	4.7	210	243	.86
	Outdoors	with rugs,					
	etc.	...	...	7.4	274	301	.91
	Outdoors	...	...	9.3	328	353	.93
I. F....	Indoors	...	...	3.2	169	197	.85
	Outdoors	with rugs	...	4.9	260	288	.90
	Outdoors	...	...	5.2	274	299	.91
L. H.	Indoors	...	...	7.5	320	343	.93
	Outdoors	...	...	9.7	382	456	.83
M.F....	Indoors	...	...	6.8	264	344	.77
	Outdoors	...	...	10.1	420	549	.76

In every one the pulmonary ventilation, the CO₂ output and O₂ intake are notably increased by the "open-air treatment." In three of these subjects measurements were made on the roof first when a hot-water bottle was applied to their feet and a couple of rugs covered their bodies from the waist down, secondly when these were removed. The table shows that the cooling of the face and hands excites in them an increase of metabolism, but this increase becomes greater when rugs and hot-water bottle are removed. On still misty days when the temperature is nearly freezing, the metabolism is increased but little compared with that on days on which the temperature is the same, but on which a strong wind is blowing. This fact is illustrated by the subjoined

* With the exception of M. F., the in and out observations on whom were made on different dates. (See Table VI.).

figures taken from the table in which are set forth observations made on M. F. during exposure to winter weather:—

	Thermo- meter.		M. F. Skin-Shirt Temperature.		Pulmonary Ventila- tion per min. in litres.	CO ₂ Output per min.	O ₂ Intake per min.	R.Q.
	W.B.	D.B.	W.B.	D.B.				
<i>March 17th—</i> Hard wind, snow and sleet ...	36½	38½	17½	23½	12.3	523c.c.	647c.c.	.80
<i>March 18th—</i> Cold, still day, misty ...	35	39½	27	30	8.5	365	419	.87

It is:—

“The icy fang
And the churlish chiding of the winter’s wind
Which bites and blows upon our bodies.”

The results, given in Table XII., show that the stimulating effect of bracing days on the East Coast cliff may be almost as great as on cold wintry days on the roof in London. There must be a certain degree of increased rate of cooling in addition to the sensation of cold before any marked increase of metabolism results.

TABLE XII.
AVERAGE RESULTS.

	Atmosphere.				Skin-Suit Katathermometer.				Pulmonary Ventilation per minute in litres.		CO ₂ Output per minute in c.c.		O ₂ Intake per minute in c.c.	
	Thermometer.		Kata- thermometer.		Wet. Time in secs. 110-100.		Dry. Time in secs. 110-105.		M.F.	L.H.	M.F.	L.H.	M.F.	L.H.
	Wet Bulb. degs.	Dry. Bulb. degs.	Wet 110-90.	Dry 110-90.	M.F.	L.H.	M.F.	L.H.						
Six days—Seaside more windy and sensed as more bracing, summer.	60	62	116	321	93	77	138	113	8.6	11.0	336	353	399	344
	58	60½	51	109	57	40	66	48	10.4	14.3	386	427	454	427
Four days — Seaside gentle breeze sensed as less brac- ing, summer.	59½	62½	117	328	91	75	131	118	9.3	10.9	349	382	401	408
	59½	62	61	148	66	45	108	74	9.1	10.5	346	336	395	378
Three days—London, winter cold weather.	50	54	90	181	—	96	—	193	—	7.5	—	320	—	343
	34	36	42	93	—	63	—	128	—	9.7	—	382	—	456
Three days — London, cold windy, winter weather when outdoors.	55	59	109	281	107	—	178	—	6.8	—	264	—	344	—
	39	43	—	—	—	—	—	—	10.1	—	420	—	549	—
Ten days—Seaside, Summer	60	62½	116	325	92	76	135	115	8.8	11.1	341.5	370	400	399

The katathermometer readings indicate that this occurs when the rate of cooling of the dry bulb from $110-90^{\circ}$ is reduced from about 300 sec. indoors to or below 100 sec. out of doors. The mechanism by which body heat loss is controlled compensates for the increased cooling effect of the atmosphere within wide limits. The katathermometer readings, which were taken between the skin and shirt on the East Coast, show a cooling effect which is greater out of doors on the more bracing days. The readings were taken at the seaside with the coat open, no waistcoat was worn, and the instrument placed under a thin cotton cellular shirt. In the winter, flannel vest, shirt, and waistcoat were worn, and the instrument placed under all these. A greater rate of cooling is noticeable in the readings taken on cold winter days as compared with those taken indoors, see Table XII., but the clothes compensate largely for the greater cooling effect of the atmosphere. Out of doors in the bracing summer days on the East Coast the clothed part of our bodies was immediately surrounded by air which permitted a rate of cooling somewhat greater than that which pertained in the roof experiments on cold winter days. Indoors in London the rate of cooling in the cold winter days was less than at the seaside in the summer. The room in London was very moderately warmed by a gas fire, and the window was kept open at the top about 9 inches. The metabolism indoors at the seaside in the summer was decidedly greater than that indoors in London in the winter. More food was eaten, and a life of greater activity led at the seaside. In the cold winter days out of doors the hands and face experienced much greater sensations of cold than at the seaside.

While on cold misty still days everyone feels cold and uncomfortable, katathermometer readings show that the rate of heat loss is not great. It may, indeed, be much greater on a bracing summer day at the East Coast when the wind is blowing and the conditions are pleasant and invigorating.

Our observations show also that the oxygen use and CO_2 output is not increased on these days as it is on a bracing windy day. The cold feeling is not then due to increased body heat loss, but to cooling of the specific cutaneous nerve endings—the cold spots. In a cold mist these cutaneous nerve endings are exposed to the cooling effect of the water particles in the air,* perhaps almost at freezing temperature, and the amplitude of the sensation of cold depends on the difference between the blood heat of the skin and the cold atmosphere outside the skin. On a bracing windy day the cutaneous vessels constrict in order to reduce the heat loss, and the air in contact with the skin is relatively dry. Relatively more blood is sent to the skin on the still foggy day. Thus the temperature gradient to which the nerve organs are exposed is much less steep on the bracing day than on the cold misty day. Our immediate feelings of comfort depend rather on our cutaneous sensations than on the rate of body heat loss.

When cold misty air laden with droplets of moisture enters the nose, these droplets must be evaporated before the air can

* The heat capacity of water per unit volume is 3,000 times that of air, and the conductivity 200 times.

be warmed to body temperature. This both cools the mucous membrane of the nose and lessens the evaporation of moisture from it. In this fact we may perhaps find the explanation of why sudden changes of weather and the going from hot rooms to cold damp air may start "colds" in the head.

The effect of exercise and sea bathing on L. H. and M. F. is shown in Table XIII.

TABLE XIII.

Subject.	Pulmonary Ventilation per minute in litres.	CO ₂ output per minute in CC.	O ₂ used per minute in CC.	—
M. F.	25.5	1108	1208	While riding one-third mile along cliff at rate of 1 mile in 4 mins. 42 secs.
	22.6	1103	1218	While doing Swedish exercises, 50 movements (10 movements, 5 different exercises) in 3 mins. 19 secs.
	7.4	280	329	6.20 a.m.—Resting on couch before bathing before breakfast.
	72.0	2527	2506	6.45 a.m.—Bathing, few strokes in rough water.
	8.4	337	374	8.45 a.m.—Resting on couch after breakfast.
	25.6	1065	1257	12.20 p.m.—Walking 225 yards in 2½ minutes (3 miles per hour approximately). A quiet morning.
L. H.	5.2	2438	2464	Running up sand cliff in 54 secs.
	6.8	264	306	6.25 a.m.—Resting on couch before bathing before breakfast.
	96.3	3804	3361	6.45 a.m.—Bathing in sea rough and cold.
	8.2	301	345	12.25 p.m.—After resting on couch 5 minutes. Had been analysing gases all morning.
	24.0	1051	1138	12.50 p.m.—Walking 200 yards in 2½ minutes (2.7 miles per hour approximately).
	9.8	376.3	382	2.40 p.m.—Resting out of doors in sun and wind.
	30.9	1340	1477	3.5 p.m.—Walking 250 yards in 2½ minutes (3.4 miles per hour approximately).

It is instructive to note how a walk of three miles an hour trebles the pulmonary ventilation and respiratory exchange while a sea bathe sends these up to more than ten times the resting value. The sea bathe increases the pulmonary ventilation to such a degree that CO₂ is washed out of the body and the respiratory quotient made greater than 1.0.

The writer suggests that an increased respiration above what is needed for the muscular effort of swimming is utilised to keep up the body temperature. So, too, on exposure to cold wind, the subject resting, the respiration is increased and for the same reason. Lyth* has found on himself that exposure, while resting,

* E. R. Lyth. Influence of thermal environment. London, 1913.

to the cold wind or cold moving water increases his pulse rate and he suggests that the contractions of the heart are brought into play to keep up the body temperature. Our observations do not show any clear evidence of accelerated pulse rate on exposure to cold, in many cases it is slightly slowed, but cold gusts of wind seem to accelerate the pulse (see Table VI., Feb. 18th and 19th).

Wolpert* employed the Pettenkofer method and made observations on the effect of wind on the water vapour and CO_2 output of his laboratory servant, comparing the effect of still air in each case. He concluded that wind increased both the evaporation of water from the skin and the output of CO_2 when the temperature of the atmosphere was between 10° and 25° C. Between 25° and 35° C. wind diminished the water vapour output and had relatively less effect on the CO_2 output. Between 35° and 40° C. wind increased both the water vapour and CO_2 output. On the naked body wind had little influence when neither cold nor warm sensations were excited, *e.g.*, at 30° C. The pulmonary ventilation was increased by wind when either the sensation of heat or cold was produced. At 35° C. moved air was more pleasant than still air to the naked resting man, and prevented him sweating. At 40° C. wind was much pleasanter, at 20° still air was the more pleasant. Wolpert says it is pleasanter to work in an atmosphere at a temperature of 25° C. and 50 per cent. relative humidity than at 17° C. and 87 per cent. humidity.

Haldane finds $31\text{--}32^\circ$ C. ($88\text{--}90^\circ$ F.) is the maximum wet bulb temperature which can be borne for several hours without marked symptoms of distress when stripped to the waist. In a good current of air $33^\circ\text{--}34^\circ$ can be borne. For fairly hard work he says $26^\circ\text{--}27^\circ$ ($80\text{--}6^\circ$ F.) is the maximum wet bulb for still air.

Zuntz† says if the heat production of the body is increased 1,000 calories by a march taken in still air at 10° C., and saturated with moisture, and the output of water vapour is increased 800 grm. this amount will be diminished 4 grm. for each 1 per cent. increase of relative dryness; for each increase of 1° C. in air temperature raised .38 grm.; and for every unit increase in wind diminished 70 grm. (He estimates the force of the wind in a scale of 10 units.)

Training has a great effect in reducing the loss of water vapour during exertion.‡ Bodily condition makes a great difference. Five subjects made the same march in uniform loaded to the same extent. The slimmest lost 953 grm., and the fattest and most solidly built 2,575 grm. of water vapour.†

Wolpert§ found that between 10° and 15° C., and up to 20° C., with relatively dry air, the water vapour output of the body was increased very little by work done at the rate of 5,000 mkg. per hour. Between 20° and 30° C. the effect of this rate of work on the vapour output was greater both in the case of relatively dry and moist air. With temperatures higher than 30° C., the increase of vapour output on doing work—compared to the resting value—

* "Arch. f. Hygiene," vol. xxiii, p. 206.

† "Lehrbuch der Physiologie des Menschen," Zuntz and Loewy, p. 713. Leipzig, 1909.

‡ Army Report on two Exper. Marches, col. 7182, 1913.

§ "Arch. f. Hygiene," vol. xxxvi, pp. 203, 204.

was less. He concludes that the increase due to work is greatest when the atmosphere causes no sweating in the resting man but work does.

The relative dryness of the air is most important in hot atmospheres. The three factors which make effective work possible are (1) dryness of the air, (2) the taking off of clothes, (3) air movement. According to Wolpert a naked man working in still air is worse off than a clothed man working in air moving at the rate of 8 metres a second. Clothed, at 33° C., in relatively dry air, a man can do at most half the work he can do naked in moist air; clothed, at the same temperature, in moist air, he can only do at most quarter of what he can do naked.

The essential thing is to keep down the saturation of the air in contact with the skin. The air entangled in the clothes becomes warmed up to body temperature, and saturated with moisture if there be no wind to drive it away.

Wolpert* concluded, from a series of observations made with a Robinson anemometer, that the velocity of the wind in the neighbourhood of houses, especially in front of the windows and in courtyards, seldom exceeds 10 per cent. of the velocity of the free wind on the roof, and generally reaches a far smaller and even only a fraction of a percentage. He found the effect of the wind was less as he proceeded from the roof to the second, and thence to the first and ground floor.

Eddies from the walls must neutralise the effect of the wind on the cups of the anemometer, and this instrument cannot therefore give a true measure of the effect of the wind in so far as it affects the rate of cooling of the body. He concluded from his observations made respectively on the ventilation of isolated country houses and penned-in town houses that the former receive about 50 per cent. more ventilation. A country house, he says, received as much ventilation in summer as an artificially-heated house in Berlin in winter.

TABLE XIV.
AVERAGE KATATHERMOMETER READINGS OBTAINED OUTSIDE THE
LONDON HOSPITAL MEDICAL COLLEGE.

Wet Kata- thermometer. 110-90. Seconds.	Dry Kata- thermometer. 110-90. Seconds.	S.S.W. wind, rain at times. W. B. 47. D. B. 48.
42	86	Roof.
37	84	In front of window, 3rd floor, South (windy) side.
42	95	" " 2nd Floor " "
45	92	" " 1st Floor " "
70	156	" " 3rd Floor, North side.
69	154	" " 2nd Floor, North side.
56	145	" " 1st (ground), North side.
50	107	" " 3rd Floor, West side.
60	120	" " 2nd Floor, West side.
65	145	" " 1st Floor, West side.
65	156	" " 3rd Floor, East side.
67	154	" " 2nd Floor, East side.
65	137	" " 1st Floor, East side.
54	114	In middle of Hospital garden.

* "Arch. f. Hygiene," vol. lii, pp. 22, 46.

Observations (Table XIV.) made by us (M. Flack and L. Hill) with the katathermometer show that the rate of cooling in front of the windows of the third and second floors on the windy and exposed side of the London Hospital Medical College is little less than it is on the roof. The eddies which neutralise the turning moments of an anemometer produce cooling of the katathermometer or human body and the difference of results obtained by us show how inefficient an instrument the anemometer is for determining the effect of movement of air on the human body. By our feelings we know that the effect of the wind is not reduced on the face of our houses or in courtyards to an insignificant percentage of that which pertains on the roof. We regard the katathermometer as a far more reliable and sensitive instrument.

The results detailed above lead the writer to conclude that the curative influence of open-air treatment and exercise depends on the increased metabolism of the body which is accompanied by a more ample ventilation of the lungs, more vigorous circulation, better appetite and digestion and lessened bacterial decomposition in the large bowel. He suggests that it is rather by these ways than by auto-inoculation that the beneficial effects are obtained in the treatment of phthisis. He urges that the movement of the air, producing an adequate cooling of and stimulating effect on the skin, is the prime factor in ventilation, and that crowded tenements and cities owe their deleterious effects to the withdrawal of the citizens from the adequate action of moving air and sun light, and not to any chemical impurity* of the atmosphere which they breathe. There seems to be no advantage in open-air treatment on cold damp days when the atmosphere is still and saturated with moisture. Exposure to such an atmosphere produces a sensation of cold owing to the water vapour in the air which cools the nerve endings in the warm skin of the face and hands; it does not produce the advantageous increase in metabolism or the stimulating effect which is produced by air movement acting on the whole cutaneous surface. Bracing places are those where the metabolism is increased most by free movement of cool and not too humid air. Sanatoria should not be placed in situations so sheltered that the air is apt to be still and overladen with moisture. It is inadvisable to surround suburban houses with trees and shrubs which blanket them with a stiller and moister air. The beneficial effect of garden cities, as far as atmosphere goes, is to be sought in the freer movement and greater relative dryness of the air both inside and outside the houses. It is well known that artificial methods of warming cannot be applied with any advantage to the raising of animal stock, and such methods should be so used by man as to diminish to the least degree the energy output of his own body, commensurate with his efficiency in work. Over-heated rooms and still air decrease the activity of the body furnace and so lead to lessened vigour and resistance to disease. Particularly is this the case if over-eating accompanies over-heating, for the food eaten is not required to keep the body warm, and undergoes bacterial decomposition in the bowel with the consequent deterioration of health. The over-heated air of

* Leaving on one side the question of dust in the atmosphere.

rooms with the rapid changes of temperature from this air to the outside winter air leads to the disturbed function of the respiratory mucous membrane, with the consequent acquisition of "colds" and respiratory infections. It is not the cold outside air which causes the trouble, but the over-heated atmosphere of the room. The general belief that exposure to cold is the cause of all trouble is greatly to be deprecated. So far as real evidence goes, those who expose themselves freely to open air and cold weather become hardy and vigorous and do not take "cold." Excessive protection from cold weather by over-clothing, over-heating, and shutting out of wind lessens immunity and increases the susceptibility to such diseases as pneumonia and phthisis. The evidence of this research is in favour of open-air schools, open workshops, garden cities, and means of affording sedentary workers opportunities of open-air exercise to counteract the effect of their employment in still warm atmospheres. When it is generally realised that it is the physical and not the chemical conditions of confined atmospheres which influence health and happiness, a vast improvement in the condition of home and industrial life will be effected.

APPENDIX.

During the execution of this research Mr. O. W. Griffith and the writer have invented an electrical instrument—the Caleometer—designed for the same purpose as the katathermometer. By its automatic action it indicates the amount of heat-energy required to keep a small coil of wire at body temperature. The oscillations of the indicator show the cooling effect of moving air and the variations of air currents. The instrument is adjusted under comfortable and healthy conditions of the atmosphere such as pertain to an ideal spring day, the indicator then pointing to the middle of the scale and oscillating to and fro with the gentle and pleasant movement of the air. If the conditions of a room are such that the rate of cooling of the human body, at either foot level or head level, is too quick or too slow for comfort, the indicator of the caleometer shows this by pointing in the one case to the right, and in the other case to the left of the scale. If the atmosphere is still and monotonous, the oscillations of the indicator will be small and few in number. The action of the instrument is simple. It consists essentially of a coil of wire having a high temperature coefficient. This is balanced at the body temperature against other coils in a Wheatstone bridge which have a zero coefficient. A current of electricity is sent through this arrangement from accumulators or direct from the mains, at a pressure of about 8 volts. If the temperature of the caleometer coil tends to increase above the balancing point a relay actuates an automatic rheostat in such a way as to diminish the main's current, and contrarily, should the temperature tend to fall the action of the automatic rheostat increases the current until thermal equilibrium is again established. A watt meter is placed in series with the coil, and this registers the rate at which electrical energy is being supplied at any instant so as to compensate for the loss due to convection, draught, etc. In many cases, as in works, factories—*e.g.*, spinning mills and weaving sheds—and public institutions, it is desirable to have a permanent record of the indications, and for this purpose a self-recording watt meter can be used, which, by tracing a curve on a roll of paper driven by a motor, registers the changes in the conditions of the atmosphere during 24 hours. The records of any number (up to eight) of caleometer coils, placed in different parts of a factory, can be taken on the same roll.* The instrument is seen in Fig. VII.

* The instrument is made by Robert W. Paul, Newton Avenue Works, New Southgate, London, N.

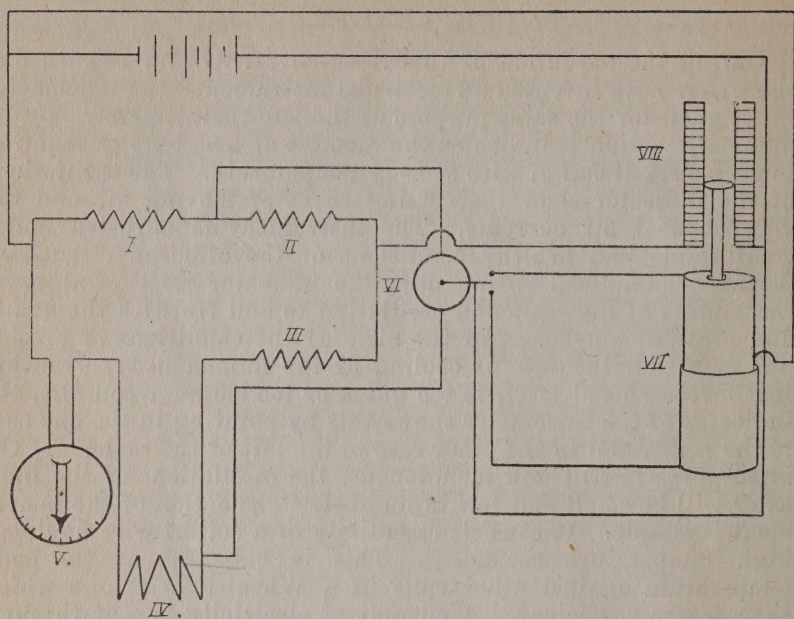


FIG. VI.

DIAGRAM OF THE CALEOMETER.

I., II., III. and IV. are the arms of a Wheatstone Bridge. When the caleometer coil IV. becomes warmer than 40° C. the index of the galvanometer VI. (used as a relay) goes upwards in the diagram and completes the circuit which includes the upper half of the electro-magnetic coil VII., the soft iron plunger moves then upwards and increases the resistance in VIII., less current then passes and the coil IV. cools. When the caleometer coil IV. cools below 40° C. the index of the relay VI. moves downwards and completes the circuit which includes the lower half of the coil VII. and this pulls down the slider and lessens the resistance in VIII. V. indicates the watts or calories required to keep IV. at 40° C.

FIG. VII. (OPPOSITE).

THE CALEOMETER.

A, caleometer coil. B, watt meter. C, travelling slider. D, magnetic coils surrounding soft iron plunger which moves in oil bath. A string passes from the plunger over a pulley wheel on the slider to a counter-balancing weight and actuates the slider. E, the galvanometer acting as relay.

For investigating the rate of cooling produced by evaporation of moisture the caleometer coil is surrounded with a muslin jacket which is kept moistened by a tape hanging in a pot of water. The caleometer will enable the meteorologist to record the daily variations of the rate of cooling produced by atmospheric conditions, and the writer is confident that records will be obtained which will throw light on the causation of those feelings which lead us to define the weather as pleasant, unpleasant, bracing, muggy, etc.

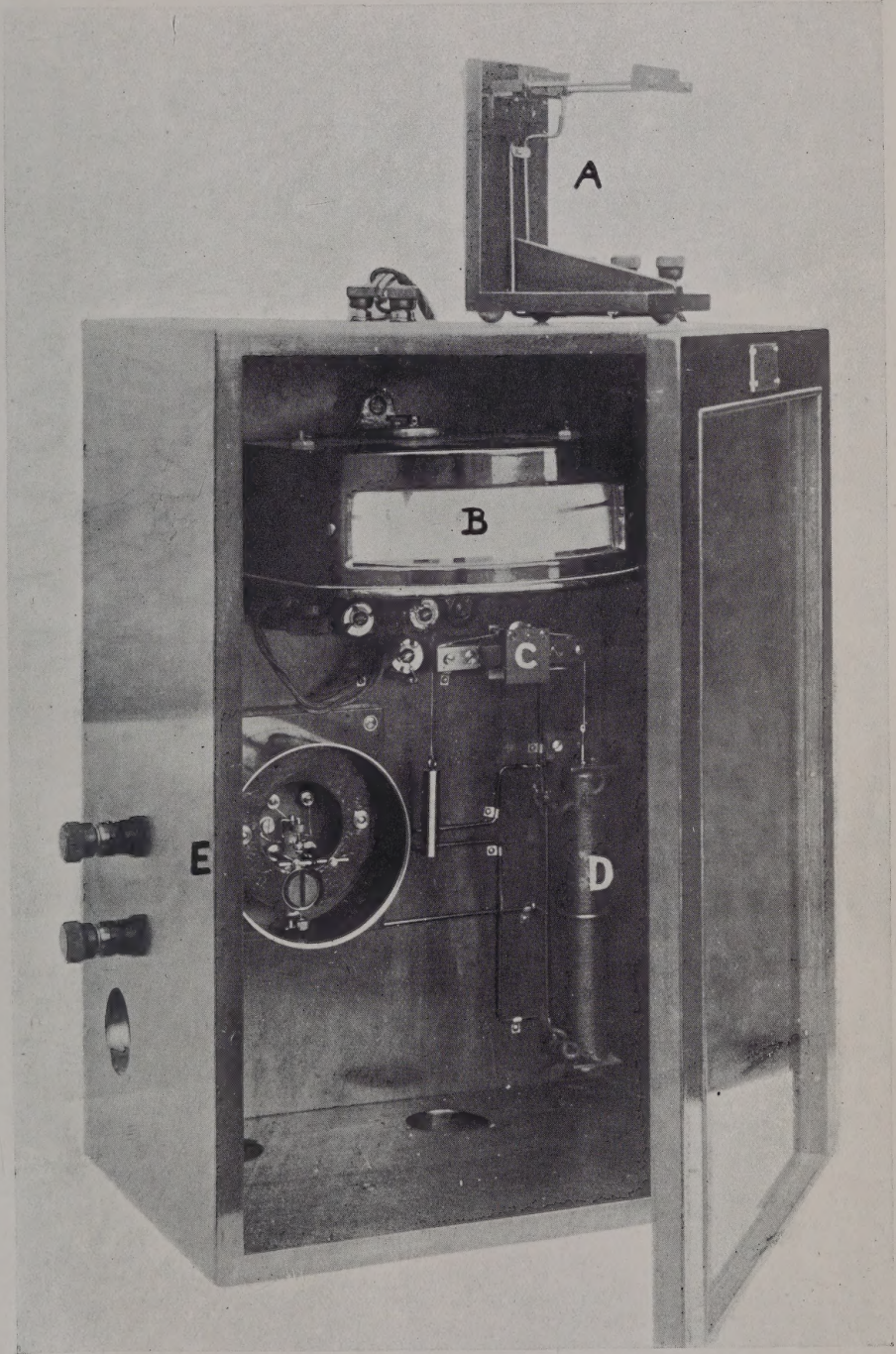
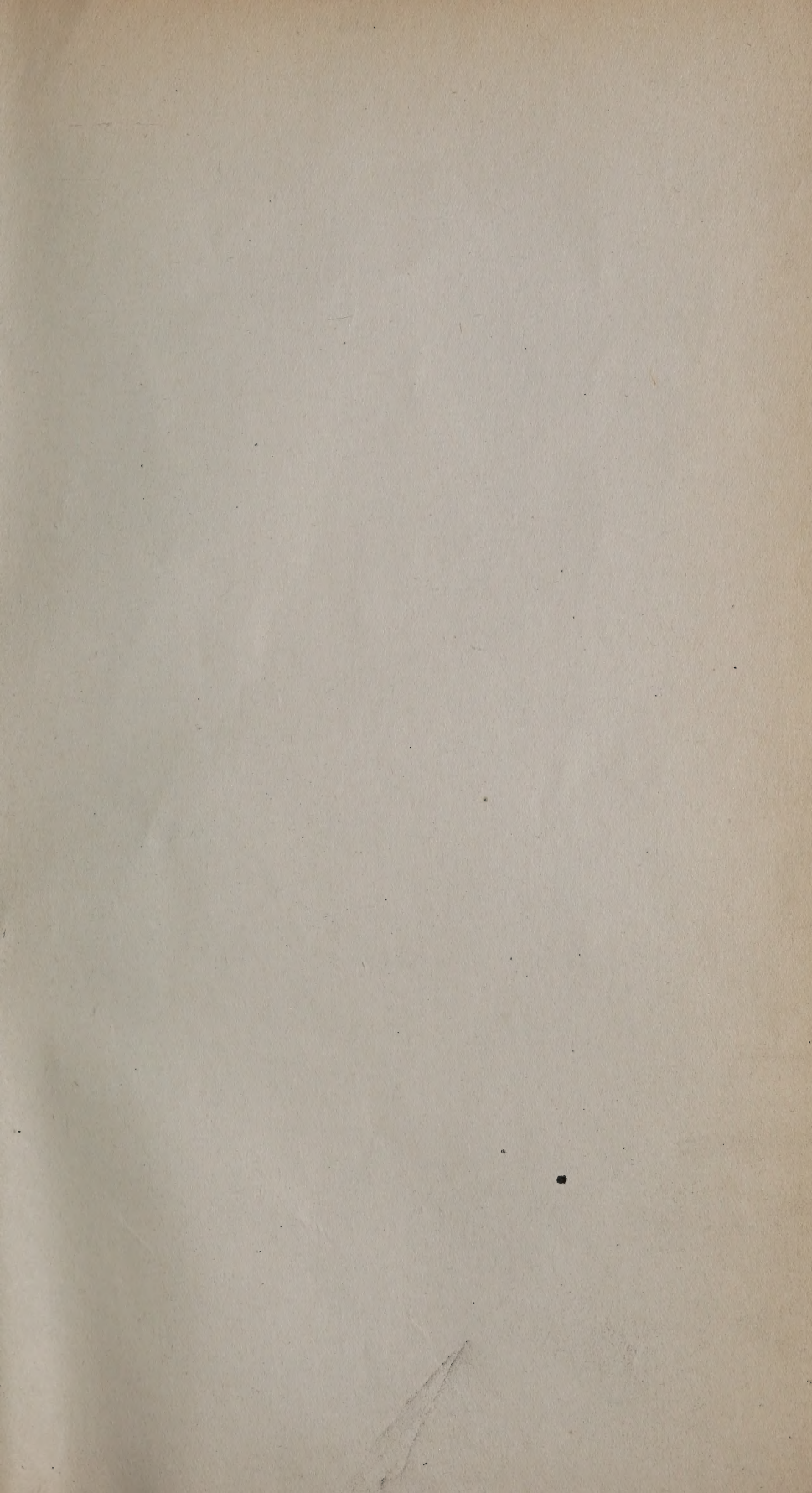


FIG. VII



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